AUSTRALIA IN THE WAR OF 1939-1945

SERIES FOUR

CIVIL

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THE ROLE OF SCIENCE AND INDUSTRY

AUSTRALIA IN THE WAR OF 1939-1945

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THE ROLE OF SCIENCE AND INDUSTRY

by

D. P. MELLOR

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PREFACE

THIS volume is intended to be an account, intelligible to the general reader, of the part played by science and industry in the defence of Australia during the war of 1939-45. Of necessity it must cover a range of subjects so wide that to do them justice would require almost as many writers as there are chapters. Expert knowledge of the diverse subjects that a volume such as this must attempt to cover is beyond the competence of any one person. Many scientists find it difficult enough to write about their own special subjects in a way that will be intelligible to the layman. To attempt to deal in this way with subjects outside one's special fields is still more difficult.

I have been given an entirely free hand in the selection of subjects to be covered—for selection there had to be. This selection and the relative emphasis given to the subjects chosen inevitably reflect my own outlook and interests. They do not, however, in any way reflect my own wartime activities: at no time have I been a member of staff of any government department or private firm which figures prominently in the story. I have tried to hold the balance evenly not only between government and private industry but between Commonwealth and State and between the States themselves. It would have been impossible to write this account without mentioning some organisations and people by name; the problem was to know just how many should be mentioned. I regret that it has not been possible to include the names of all firms and individuals who made significant contributions to Australia's defence effort. The omissions are unintentional and, it is hoped, pardonable.

My sources of information have been many and varied; they include the Minutes of the War Cabinet and of a number of specialist committees; scientific journals, newspaper articles, pamphlets, public addresses, accounts of wartime work published by private firms, the files of government directorates, histories of wartime directorates, and personal interviews. Only in rare instances did private firms, for reasons best known to themselves, decline to cooperate in supplying information. The great majority went out of their way to help me.

At the risk of leaving myself open to criticism for including explanatory material more properly belonging to a textbook, I have endeavoured to make the story intelligible to the layman and to supply him with enough detail to make it interesting as well. Where it has been necessary to simplify technical matters I have tried to do so without sacrificing scientific accuracy. It would have been impracticable to describe manufacturing processes in detail. As a general rule the most that could be done was to explain the significance of a manufacturing project, some of the difficulties encountered, and any unusual technical feats achieved in overcoming them. Scientific and industrial history demands a somewhat less restrictive chronological treatment than military history. The achievements of Australian science and industry during 1939-45 were often strongly

influenced by events that took place many years before. For this reason the first two chapters attempt to trace the growth and development of some of the scientific and industrial organisations which played a significant part in the events of the war years.

The record of these events is not a simple success story, though I may at times create the impression that it was. Mistakes and misjudgments were of course not uncommon but very few of them have been clearly disclosed and analysed in official documents or in the accessible records of private industry. Attempts to arrive at an impartial view of misjudgments and conflicts of opinion, on the basis of information gained solely through personal interviews long after the events with which they were concerned took place, proved, as a general rule, futile. Very few individuals show any great inclination to admit and analyse their mistakes for the benefit of a permanent record. For obvious reasons, firms that failed badly in any wartime enterprise have not been named. As often as not failure was due to the firm's unfamiliarity with, and consequent underestimation of, the difficulty of the task it had undertaken.

Owing to the exigencies of war, individuals sometimes found themselves placed in responsible posts for which their scientific and administrative qualifications, though better than those of any one else available, were not really suitable. In these circumstances it hardly seemed fair to criticise adversely efforts that did not come up to expectations.

The military significance of any industrial enterprise was not the only criterion for its inclusion in this volume. Indeed whole chapters have been given over to projects such as the manufacture of tanks and torpedoes which proved to have no direct wartime military value. All too often by the time the materials for a project had been ordered and the administrative organisation set up, the manufacturing capacity assembled and the technological difficulties overcome, the need for it had passed. War does not adapt itself to the industrial pace of a small and relatively inexperienced nation. I make no excuse for discussing quite fully projects which, although they did not contribute to Allied military strength, often made a real contribution to Australia's strength as an industrial nation.

Similar seemingly wasted effort took place in a number of scientific investigations to the discouragement of the scientists concerned. However, neither they nor the industrialists should have been discouraged by these experiences. War is inherently wasteful. The course and needs of war are governed by the action of two opposing sides, and it is only in relation to one of these that any kind of detailed forecast of military requirements can be made. Even these forecasts can be completely upset by some quite unexpected move of the enemy. Every soldier is constantly engaged on difficult, exhausting and sometimes dangerous activities that prove to be fruitless. Much of a soldier's time is spent in preparation for events that never happen. It should therefore occasion no surprise that much industrial effort was also spent in preparation for emergencies that never arose. I have tried to take a longer view of such efforts, and in the last

chapter have attempted to show briefly some of the lasting benefits that have accrued from the legacy of wartime experience.

This volume could not have been written without the generous cooperation of many experts. Each chapter has been read and criticised by men who played an active and prominent part in the events described. Any merits the volume may possess are due to their help; its defects are my own responsibility. It would be impossible to acknowledge here the help of everyone who has supplied information or checked details, but I should like to take this opportunity of making a collective acknowledgment of my indebtedness. The help of those who advised on the individual chapters is acknowledged in the appropriate place.

I am especially grateful to Sir John Jensen for the privilege of reading the early drafts of his personal memoirs and for his constructive criticism and advice. In collecting and making available the files of the Department of Munitions he has spared no effort. It was largely through Sir John's foresight that many branches of the department compiled their own histories; these proved of great value, particularly in giving me a general background on which to base my study of the various projects.

To Major-General J. W. A. O'Brien, who read many chapters, I am greatly indebted for discussions which helped me to understand the army point of view on questions of munitions supply. I have not always accepted his estimate of the value of efforts made by scientists and engineers, and if at times I differ from generally-accepted army views, this must not be attributed to General O'Brien.

On the many problems which inevitably arose in a volume of a kind new to official war history, the General Editor, Mr Gavin Long, never failed to give me the benefit of his wide experience in historical and literary matters. I owe a great deal to his generous help and encouragement. In the early stages of the work I received considerable assistance from Miss Joyce Fisher, who as research assistant did much to sort out information from the War Cabinet Minutes. Mr Hugh Groser drew all the diagrams and maps. I am indebted most of all to my literary assistant, Miss Sylvia Mossom, who prepared the manuscript for the printer, compiled the biographical notes and the index, and checked innumerable details. She also read the proofs and did much to reduce the number of verbal infelicities and obscurities in the explanation of scientific and technical matters.

D.P.M.

Sydney, 1st July, 1957

CHAPTER 1

BETWEEN THE WARS

IF the origins of the industries and scientific organisations that played an important part in Australia's defence during the great war of 1939-45 are sought, it will be found that in many instances they can be traced back either to the war of 1914-18 or to the period immediately preceding it, when the spirit of federation began to influence defence policy. Since many of these industries and organisations came into being as a result of the lessons learned from the experience of war, any account of their activities in the second conflict should begin where the *Official History of Australia in the War of 1914-1918* left off. In that history no volume was devoted primarily to science and industry.[1] It will therefore occasionally be necessary to refer briefly to events that took place during or before the war of 1914-18, but no more will be told than is necessary to an understanding of later events.

Stated in the most general terms, the technological challenge that Australia had to meet in the war of 1939-45 was for mass production, on a nation-wide scale, of materials and articles of a higher degree of complexity and accuracy than had before been attempted in Australia. Mass production of the kind and on the scale witnessed in Australia during these years could not have been achieved without a great deal of foundation work, which of necessity was spread over many years.

No single volume could set out the story of all the many industries involved in the great industrial expansion which, after slowly gathering way between the two wars, halting for a while during the economic depression which began in 1929 and extended in effect well into the thirties, culminated in the great defensive effort of 1939-45. The most that one can hope to do is to sketch in broad outline a few of the important scientific and technological influences at work and then briefly describe some of the main achievements.

The process of making large numbers of one type of article or component exactly alike in shape and size, began not with the industries of peace—the manufacture of motor cars, radios and refrigerators—as one might be tempted to guess, but with the supply of weapons of war. The technique of mass production was industry's response to the need to produce large quantities of arms in the shortest possible time, and was applied first in 1793 by Eli Whitney, a contractor to the United States Government for the supply of small arms. An essential feature of the revolutionary method introduced by Whitney was that it achieved replication of component parts by mechanical means—by the use of jigs and fixtures. In its simplest form a jig was a metal pattern to guide a tool while it was cutting

[1] Ernest Scott's *Australia During the War*, which was Vol. XI of the *Official History of Australia in the War of 1914-1918*, dealt briefly with these subjects.

or drilling; since it guided the cutting tool along the same path each time, the metal or wooden parts thus machined, which were held in position by fixtures, must be replicas of each other. By means of this technique he was able to effect considerable economies in costs and skilled manpower.

Repair of Whitney's weapons could be easily effected in the field because any part could be replaced by another exactly like it. Furthermore, military authorities having satisfied themselves that the performance of a particular weapon was satisfactory, the practice of adopting it as a sealed pattern, and demanding that all others be exactly like it, became firmly established.[2]

The first association of the Government in Australia with mass production concerned the manufacture of small-arms ammunition, which was required to the number of many millions of rounds, each of which had to be finished off to very fine limits of measurement. The ammunition was manufactured for the defence forces of the State governments by the Colonial Ammunition Company, established in Victoria in 1888. The next phase was the manufacture of small arms.

As the first step in a plan for the unified defence of the Commonwealth, conceived shortly after Federation, the Government decided to build a small-arms factory at Lithgow, New South Wales, where the first Australian steel industry of any significance was just getting on its feet.[3] The intention was that a rifle (the Short Lee-Enfield .303) should be made at Lithgow and the ammunition for it in Victoria, while a factory would be built at Maribyrnong, Victoria, for the manufacture of cordite and mercury fulminate. The latter was the first of the two factories to be completed. It was designed by Mr Leighton,[4] an explosives expert who, after some years as manager of a similar factory in India, was engaged by the Australian Government for this purpose. Leighton remained in Australia to become the factory's first manager and thus began an association that was to last more than thirty years and entitle him to be regarded as the founder and principal architect of the Australian munitions industry.

Tenders for the small arms factory, returnable in March 1909, were called for, and were submitted by three British engineering firms and one American, whose quotations were as follows:

Birmingham Small Arms Co Ltd	£150,000
Archdale Machine Tools Co Ltd	£100,000
Greenwood and Batley Ltd	£69,000
Pratt and Whitney Co, Hartford, Connecticut, U.S.A. .	£68,144 8s 3d.

It was a disappointment to the British engineering industry when the Australian Government announced its decision to accept the tender of a foreign country.[5] But there were sound reasons behind the decision, the most

[2] The first attempt to standardise weapons by means of a sealed pattern, though not based on the use of jigs, was made by Charles I.

[3] Iron was first smelted in Australia at Mittagong, NSW, in 1852.

[4] A. E. Leighton, CMG. Officer of Department of Military Supply, Govt of India, 1903-09; General Manager, Aust Arsenal, 1916-22; Controller-General of Munitions 1922-37, 1938-39; Consultant on Explosives, Ministry of Munitions, 1940-46. Of Melbourne; b. London, 17 Jun 1873.

[5] J. K. Jensen, "Development of Munitions Production in Australia". Address to Institute of Industrial Management of Australia, 1 Jun 1943.

important being that the Pratt and Whitney[6] Company had been able to convince Engineer Commander Clarkson,[7] adviser to the Commonwealth Government on this matter, that its system of "repetition manufacture" (as the mass production system was then known) was very much in advance of the British system. The company was already supplying machines and tools to British establishments making service rifles.

In July 1909 Pratt and Whitney undertook to supply all the equipment, including tools, jigs, fixtures and gauges and a complete tool-room plant, the first of its kind in the Commonwealth, for maintaining and reproducing them. To contract to supply plant for a complete small-arms factory was something new, and the Australian project attracted world-wide interest. The plant was to be capable of manufacturing rifles whose components would be interchangeable not only with those of all rifles made in Australia, but with those made in Great Britain, because the existing stock of rifles (to the number of many thousands) had been manufactured in Britain. Pratt and Whitney experienced difficulty in meeting both requirements but in neither case was it due to their lack of engineering skill. To make clear what these difficulties were it will be necessary to digress a little.

The degree of perfection to which the mating of different components of an article was required varied considerably in different manufactures, being much less for ploughs and motor-car bodies than for rifles, machine-guns and internal combustion engines. The most direct method of discovering whether components were interchangeable and would mate satisfactorily with others was, of course, to try them out by assembling the finished article. In methods of mass production as exemplified in the assembly-line technique, it was essential to know with certainty beforehand that components would mate satisfactorily when assembled.

In the manufacture of internal combustion engines, for example, it must be certain that any one of ten thousand pistons, wherever they were made, would give a true and satisfactory fit with any one of a similar number of cylinders for a particular make of engine. The same kind of thing applied to rifles and guns and their ammunition. Such interchangeability was possible only if the dimensions of cylinders and pistons were controlled within far narrower limits than could be fixed by measuring scales (rules) or callipers. The departures from specified dimensions permitted in the manufacture of rifles and machine-guns were usually one or two thousandths of an inch, but sometimes even a ten-thousandth of an inch, depending on the component concerned. An effective method of controlling dimensions of components to within these limits of accuracy was by the use of limit gauges. The aim of limit gauging was to ensure that a piston, for example, should have a diameter not larger than a specified upper limit nor smaller than a specified lower limit. In this instance the gauges could consist of two holes in a sheet of metal, one with a diameter exactly equal to the upper limit and the other, a few thousandths

[6] This Whitney was descended from a branch of the same family as Eli Whitney mentioned above.
[7] Later Engineer Vice-Admiral Sir William Clarkson, Third Naval Member.

of an inch smaller in diameter, exactly equal to the lower limit. Then a piston which went into the larger hole but failed to enter the smaller must have a diameter within the prescribed limits, and no measurement with a micrometer was necessary. If only one piston of the particular size was required, it was cheaper to measure its diameter directly with some sensitive device such as a micrometer, but where hundreds of thousands of pistons of the same size were required, some system such as limit gauging was essential. The diameter of a cylinder could be controlled in a similar way to ensure a true fit with the piston.

One of the difficulties experienced by Pratt and Whitney arose from the fact that tolerances specified in the British drawings did not permit interchangeability. In other words, the tolerances were too great.[8] This was easily overcome by reallotting tolerances. After these adjustments had been made it was found that components were still not interchangeable with those of rifles made in Britain, six of which had been sent to Pratt and Whitney by the Australian Government. The firm now became seriously concerned, and after much trouble it discovered an astonishing state of affairs: dimensions marked on British drawings were in terms of two different units of length. For dimensions less than 2 inches the so-called "Enfield inch" was used;[9] above 2 inches dimensions were stated in terms of the inch derived from the Imperial Standard Yard. By some oversight the American firm had not been told about the Enfield inch, and naturally enough did not suspect such a lack of standardisation in measurement. The sizes of all Pratt and Whitney's gauges were fixed in terms of the inch derived from the Imperial Standard Yard. Only after a good deal of money had been spent were matters put to rights, but interchangeability with British rifles was finally ensured.

In 1910, while the factory was being built at Lithgow, a group of young men, including an accountant and six engineers, was sent to Pratt and Whitney for training in factory administration and in methods of mass production. Several members of this team took a prominent part in the Australian munitions industry: Mr Finlay[1] became a leading authority on machine tools and gauges and Divisional Manager of the Lithgow factory; Mr J. D. Statton was Divisional Manager of the New South Wales Ammunition Factory during the war of 1939-45; while the accountant, Mr Jensen,[2] was later to become Secretary of the Department of Munitions. For many years to come large numbers of engineers who ultimately

[8] The permissible limits for the dimensions of a piston, for example, might be 2.746 to 2.742 in, and of the cylinder into which it had to fit 2.744 to 2.748 in. A 2.746-in piston would not fit into a 2.745-in cylinder; that is, the tolerances overlap.

[9] A standard of length used by the Royal Small Arms Factory at Enfield, England. Employment of two different standards of length did not seriously matter while it was confined to the one manufacturer, though it did not make for efficiency.

[1] J. Finlay. Assistant Manager, Small Arms Factory, Lithgow, 1935-41, Acting Manager 1941-42; Divisional Manager, Govt Small Arms Factories, 1942-47, General Manager 1947-50. B. Kilmore, Vic, 11 May 1885.

[2] Sir John Jensen, OBE. Chairman, Defence Contract Board, 1923-39; Controller of Munitions Supply 1937-39; Assistant Secretary, Depts of Supply and Munitions, 1939-41; Secretary, Dept of Munitions, 1941-48; Chairman, Secondary Industries Commission, 1943-49; Secretary, Dept of Supply and Development, 1948-49. B. Bendigo, Vic, 20 Mar 1884.

attained high executive posts in industry passed through the Small Arms Factory.

In the war of 1914-18 Australia was not sufficiently industrialised to do more than provide her armies with food and clothing, and rifles and ammunition. The war threw into sharp relief her dependence on outside sources for guns, gun ammunition and high explosives. Government and defence authorities alike took the view that it was high time Australia made these items herself, and in 1915 began to consider plans for the construction of an arsenal at Tuggeranong, in the Federal Capital Territory. Events in Britain, however, altered the position. Britain was faced with an almost disastrous shortage of ammunition, and instead of waiting for its own plans to mature the Australian Government decided to arrange to give her immediate help. This was done by encouraging commercial engineering firms to contract to make 18-pounder shell bodies. After some £120,000 had been spent on this project it was suddenly stopped at the request of the British Government.

Although the decision was a disappointing one, the reasons behind it were sound enough. Australian engineering industry did not possess either the numbers of men trained to work with high precision or the amount and kind of equipment needed to achieve any worthwhile output; the planned local production of 3,000 shell bodies a week was quite insignificant compared with the 600,000 a week that Canada had achieved by mid-1916. In these circumstances it was decided that Australia's contribution to the technical and industrial side of the Empire's defence could be best given in the form of men and materials. The latter was represented principally by the export of shell steel. The most valuable practical help, however, was given through various schemes under which trained men were sent to the United Kingdom. Under one of the first of these, initiated by Mr Leighton with the approval of the Commonwealth Government, more than 100 chemists and draughtsmen were recruited to work in Britain's explosives factories. Later, at the suggestion of Professor Barraclough,[3] a scheme known as the Munition Workers' and War Workers' Scheme, embracing a much wider range of skills, was introduced.[4] Many of the engineers recruited for work in the United Kingdom under these and other arrangements, later exercised a considerable influence on the progress of Australian defence industries.[5] Their experience of the principles of factory construction, layout, and general organisation, and of the techniques of manufacture—in short, of mass-production engineering—provided in large measure the foundation upon which the Australian munitions organisation was subsequently built.

[3] Col Sir Henry Barraclough, KBE, VD; BE. Prof of Mechanical Engineering, Univ of Sydney, 1915-42. B. Sydney, 25 Oct 1874.

[4] A fuller account of these schemes has been given by Scott, p. 264.

[5] One group included a number of permanent officers of the Defence Dept who later became managers of different sections of the Australian munitions industry. Foremost among them were Marcus Bell (Chemical Adviser), Col H. B. L. Gipps and Major A. J. Coghill (Inspection and Equipment Branches), A. A. Topp (Cordite Factory), J. H. Wrigley and W. M. B. Fowler (Ammunition Factory), M. M. O'Loughlin and F. S. Daley (Ordnance Factory, Maribyrnong), and R. H. Doyle (Small Arms Factory).

Leighton, then Manager of the Government Explosives Factory at Maribyrnong, was sent to England to study the latest developments in the manufacture of cordite. He had not long been engaged upon this when the British Ministry of Munitions requisitioned his services as technical adviser for the great new explosives and filling factories then being built.

In the meantime the Commonwealth Government returned to the question of establishing an arsenal at Tuggeranong. Leighton, who had extensive experience in the production of munitions, gained some years earlier in India, was appointed general manager of the proposed arsenal. However, since it was obvious that a central arsenal could make no timely contribution to the defence of the Empire in the war period, it was agreed that Leighton should remain in Britain until the war was over. Towards the end of his stay he began, at the direction of the Commonwealth, to plan the reorganisation of the supply of munitions in Australia, selecting from the Australian scientific and technical men then in Britain a number of experts who were given special opportunities to familiarise themselves with the different types of engineering equipment and scientific instruments likely to be needed for the manufacture of munitions.[6]

On returning to Australia Leighton furnished the Government with a full report setting out the results of his investigations and proposals for the reorganisation and extension of government munitions factories. His general plan departed considerably from the original scheme of one great arsenal at Tuggeranong for the manufacture of all classes of munition on a scale to meet all the demands of a modern war, and that scheme was abandoned.

Leighton was well aware of the circumstances of the disastrous shortage of munitions that had occurred in Britain in 1915, and that it was attributable largely to the fact that before the war insufficient preparation had been made to extend the manufacture of munitions to commercial industry. No one had realised the magnitude of the war that was coming. Government establishments and private armament firms proved inadequate to meet the vast demands made upon them. Until confronted with dire necessity, the Government had been reluctant to provide the large sums of money needed. Experience showed plainly that it was impracticable for any nation to make in a few great centres all the munitions it was likely to need during a long war. Modern wars, in Jensen's words, "must be fought by the whole community and not by a small coterie of experts".

Another factor that contributed to Britain's difficulties in 1915 was her failure to make the most efficient use of science. Lord Sydenham,[7] in an address to the British Guild of Science in April 1917, expressed this viewpoint:

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[6] The team included: R. E. Summers (Chemical Adviser's Staff), C. P. Callister and C. W. O. Stubbs (explosives and ammunition), W. R. Jewell and C. Blazey (metallurgy) and N. A. Esserman (physics, optics and metrology). When they returned to Australia they were joined by J. T. McCormick, A. E. Dawkins, P. R. Weldon and E. L. Sayce.

[7] Lord Sydenham, GCSI, GCMG, GCIE, GBE; FRS. Governor of Victoria 1901-4, of Bombay 1907-13; Secretary to Cttee of Imperial Defence 1904-7; Member of Air Board 1916-17. B. Lincs, Eng, 4 Jul 1848. Died 7 Feb 1933.

Our weakness and our potential strength stand plainly revealed. We can see how severely we suffered and must still suffer for our neglect in the past; and if we strive to ascertain the causes we cannot fail to reach the conclusion that our lack of appreciation of all that science—using that term in the broadest sense—could have conferred on us, lies at the root of many of our present difficulties.[8]

The general idea underlying Leighton's proposals concerning the scope and function of the Government's munitions factories was that they would meet the country's small peacetime demand for munitions, which it was hoped would be sufficient to keep them operating on an economic basis. At the same time the factories would acquire equipment, and with the help of adequately equipped scientific laboratories would develop methods of manufacture and train men so that when war came it would be possible to transfer to commercial industry the burden of the mass production of the great bulk of munitions. In this sense the government factories and commercial industry were to be complementary. The government factories would withstand as best they could the first shock of war until industry could be organised.

Government factories would of course depend on private industry for their raw materials, principally metals, alloys and the heavy chemicals needed for explosives. Australian metal-extraction industries were by now fairly well established: steel at the Broken Hill Proprietary Company Ltd, Newcastle, New South Wales; zinc at the Electrolytic Zinc Company of Australasia Ltd at Risdon, Tasmania; copper at the Electrolytic Refining and Smelting Company of Australia Pty Ltd, Port Kembla, New South Wales; and lead at Broken Hill Associated Smelters Pty Ltd, Port Pirie, South Australia. All of them either owed their existence to or had been greatly stimulated by the war of 1914-18.[9] Of heavy chemical industry there was as yet but little.

Leighton's general approach to the problems of defence is evident from remarks he made when speaking of disarmament in 1920:

An industrially developed nation cannot be disarmed. Exact knowledge of munition production, a nucleus of skilled workers, supplies and then within a few months a nation is transformed. . . . The power to retain a strong position in the world depends ultimately, not on the possession at any moment of ships, engines and munitions of war, but on the extent and variety of the nation's industries and the possession of knowledge to apply the resources of the industries quickly and effectively to the problems of war.

The government establishments were, as he put it, to be "nucleus factories", "model schools for the instruction of masters and men of outside industries". With the exception of those based on the extraction and, to some extent, fabrication of metals, Australian secondary industries were at this time not highly developed. Leighton's first concern was, therefore, not so much with an immediate use of commercial industries as with laying a firm foundation for an organisation which could teach them and make use of them should the need ever arise. He was of course anxious that

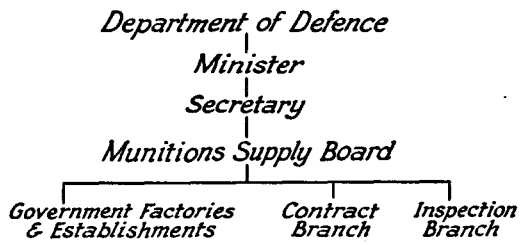
[8] British Guild of Science, London, Eleventh Annual Report, p. 66 (1917).

[9] Scott gives a full account of the origins of these industries.

those industries likely to be of use for defence should be encouraged wherever possible by the judicious application of protective tariffs.

He was confident that by the time full effect had been given to his plans for the government factories, commercial industry would have reached a stage in its development where it would be capable of rapid expansion and could be counted upon to make an appreciable contribution to defence in time of war. More specifically, his plans provided for the setting up of government laboratories and factories, for extending those already in existence, and placing them all under a central administrative body, with the idea that in a few years Australia would be able to produce, on a small scale at least, most if not all of the different kinds of munitions likely to be needed by the Services.

It was not the most propitious moment for presenting a scheme of this kind: both parliament and people were far more interested in disarmament, sincerely believing that they had fought the war to end war. Nevertheless Leighton's arguments were sufficiently cogent to induce the Government to adopt his plan, in principle at least, and to set up a body known as the Board of Factory Administration to administer existing government factories. On 13th August 1921 it was reconstituted as the Munitions Supply Board with Leighton, now Controller-General of Munitions, as its *ex officio* chairman.[1] The board's position in the organisation of the Department of Defence may be seen from the accompanying chart. Essentially a civil organisation, it was no part of the board's function to decide what kinds of munition should be made, or in what quantities; it was concerned solely with seeing that the demands of the Services were met once they had been approved by the Government. This division of responsibility between the supply organisation and the Services remains a cardinal point of policy to this day.



It will be seen that there was no place in these arrangements for supplying the Services in peace time with munitions made by private firms. Except for the period (1888-1921) when the Colonial Ammunition Company had made small-arms ammunition for the State, and later for the Commonwealth, Governments, no private firm devoted exclusively to the manufacture of armaments, such as are found in Britain and in Germany, had ever operated in Australia. The policy of the Australian Government was strongly opposed to the manufacture of munitions for profit.

Despite the prevailing popular revulsion from anything to do with armaments, one feature of Leighton's scheme was readily implemented by the Government: his proposal to set up scientific laboratories to serve as a

[1] Original members of the board were: Mr A. E. Leighton (Controller-General of Munitions Supply), Chairman; Col T. J. Thomas (Finance Secretary, Dept of Defence), Deputy Chairman; Mr M. M. Maguire (Assistant Secretary, Dept of Defence); and Mr J. K. Jensen, Secretary.

focal point for the development of the techniques used in manufacturing munitions. The opening of the Munitions Supply Laboratories at Maribyrnong in 1922 may, in fact, be said to have marked the launching of the new scheme. These were not the first laboratories to be established within the Department of Defence: they were in fact an expansion of a small laboratory known as the Defence Laboratory, which had been instituted in 1909 by Mr Napier Hake,[2] Chemical Adviser to the Department of Defence, mainly for the purpose of investigating problems relating to the manufacture and safe storage of explosives. The new laboratories were many times larger, and far wider in the scope of their activities. As organised in 1922 under the superintendence of Mr Bell,[3] they comprised the following sections: Explosives and Ammunition, Physics (including Metrology), Metallurgy, General Chemistry, Chemical Defence, Timber and Technical Information. Their functions, laid down by the Munitions Supply Board, were:

1. To maintain standards of manufacture and supply by the application of chemical and physical science.
2. To promote by research the production of defence supplies from Australian raw materials by government or civil industry.
3. To study special problems in manufacture, inspection and service use of defence stores and equipment.
4. To coordinate the control methods of laboratories attached to defence factories.

The complexity and exacting requirements of the munitions industry made it essential that there should be some centre to provide technical guidance and control. "Munitions must be of the finest tolerances to facilitate interchangeability; they must be able to withstand the stresses and accelerations of explosive power and to function with certainty and precision under the most adverse conditions. They must be safe in handling and in use; have a 'shelf life' measured possibly in years and yet be capable of being brought into action within seconds. All these place on the munitions designer and producer demands not always encountered in manufacturing at large."[4] The Munitions Supply Laboratories were designed to help the government factories meet these high standards.

Ever since munitions were first manufactured in Australia it had been the policy of the Department of Defence to adopt, as far as was practicable, British designs and specifications for all equipment used by the Services and to follow as closely as possible British technical practices. In the interests of efficiency, standardisation of the equipment of armies likely to fight side by side was essential. Maintenance and repair of equipment could be effected with far greater ease and economy if, whatever its origin, it had been manufactured with interchangeable components.

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[2] C. Napier Hake. Chief Inspector of Explosives, Vic, 1890; Chemical Adviser, Defence Dept, to 1911. B. England 15 May 1848. Died 16 Oct 1924.

[3] Marcus Bell, OBE. Chemical Adviser, Defence Dept, 1911-15; Director of Munitions 1916; Superintendent of Laboratories, Munitions Supply Branch, 1917-34. Of Kew, Vic; b. Kew 7 Jan 1881. Died 3 Jun 1934.

[4] "Industrial Mobilisation Planning", a lecture delivered by Mr J. L. Knott (Deputy Secretary, Dept of Defence Production) on 2 May 1955.

As a means of ensuring strict conformity with Imperial specifications, design and construction, and of extending the application of the mass-production techniques already in use at Lithgow, a central laboratory was set up for the maintenance of standards of measurement. No effort was spared in equipping the metrology section of the new laboratory with the best precision measuring machines available, since it was by these means that it was hoped to maintain the degree of accuracy in the manufacture of the complete 18-pounder gun, including ordnance, ammunition and waggon, then being planned as a major activity of the government factories for the next few years.

An indispensable requirement in making gauges was to be able to carry out accurate measurements of length in terms of a standard accepted by all factories whose manufactures were to be interchangeable. Throughout the British Commonwealth the Imperial Standard Yard was accepted as the standard of length. Australia became firmly linked with this system when in 1925 the first basic standards of length—two one-yard end bars, together with associated equipment, certified by the National Physical Laboratory at Teddington, England, to within one part in a million—were installed in the Munitions Supply Laboratories. The basic yard standards at Maribyrnong were periodically returned to the National Physical Laboratory for verification. Thus were laid the foundations for precision mass-production engineering throughout the government defence factories.

Additional precision instruments were installed from time to time until in 1930 it was possible to carry out a most comprehensive series of measurements. There were machines for measuring angles and forms, pitch and diameter of screws; for precision lapping and reconditioning of surface plates; and for measuring internal diameters of tubes. A 20-inch linear dividing engine and circular dividing engine provided the means for making precision scales on measuring instruments. Indirectly, through the gauging equipment used by the Inspection Service of the Defence Department, private engineering firms in Victoria contracting with the department were helped to maintain their equipment on the basis of Imperial Standards. A truly national standards laboratory serving all industry—government and private alike—throughout the Commonwealth, and whose standards had legal sanction, was yet to come.

Much of the laboratories' earlier work centred on helping new factories and contractors over their initial difficulties. They were concerned with the introduction of modifications in procedures to meet local manufacturing conditions and in materials to enable the substitution for imported materials of those of local origin. As a general rule the latter could be adopted only after thorough investigation had shown that the products made from them were comparable in all respects with those from the United Kingdom and other countries of the British Commonwealth.

In its widest sense, the term munitions embraced many items similar to or identical with those used in civil life: clothing, food, housing, transport and communication; in fact, stores of this kind might be required by the Services in greater quantities than munitions in the narrower sense

of the word, such as, small arms, guns and ammunition. Since practically every major industry was thus involved in the provision of supplies for defence, the Munitions Supply Laboratories were equipped with a correspondingly wide range of facilities for the examination of materials and products of the most diverse character.

Standards of quality in regard both to materials and to performance of equipment for the Services were then far higher than those for corresponding articles in commercial and domestic use. They still are in many respects, but then—in the early twenties—commercial engineering industry in Australia had not reached the stage where it required the strict scientific control that was necessary for munitions. Except in rare instances, private firms contracting with the Government did not maintain laboratories, even for testing raw materials and products and for controlling processes. Still fewer firms undertook serious scientific research of any kind. One of the main functions of the Supply Laboratories, therefore, was to carry out tests on raw materials such as metals and alloys required for making munitions, and to supply technical advice to private firms engaged in supplying these materials. They were equipped to examine the microstructure of metals and to test their hardness, tensile strength, ductility and brittleness. Facilities for experimental work on casting, annealing, hardening and tempering enabled factory problems to be studied without the necessity of launching expensive trials on a manufacturing scale. The laboratories' other main function was to assist the Inspection Branch of the Munitions Supply Board to ensure that finished products of the factories conformed with Service specifications.

The function of the Explosives and Ammunition Section of the laboratories was to examine both the physical and chemical behaviour of military explosives in order to assess their effectiveness and their susceptibility to deterioration. As a rule military explosives were stored for longer periods than commercial explosives, and it was essential to know what conditions must be fulfilled for safe storage. Progressive chemical tests on explosives kept for relatively short periods in special climatic chambers where severe but accurately-controlled conditions of temperature and humidity were maintained, enabled a forecast to be made of what was likely to happen to them after long storage under normal conditions. Physical tests provided a way of determining the efficiency of explosives and their sensitivity to shock.

The General Chemistry Section dealt with the chemistry of all materials except explosives and metals, mainly with a view to finding out whether they conformed with specifications. Owing to the wide range of materials that had to be tested—fuels, lubricants, rubber, leather, paints, varnishes and textiles—a high degree of versatility was necessary in the staff and equipment of the laboratory.

The first technical and scientific information service of any significance in Australia was formed at Maribyrnong, where reports on subjects of special interest, such as the manufacture of warlike supplies and their inspection, were compiled by technical officers of the department. By

means of this agency technical officers throughout the Munitions Supply establishments were kept advised on the most recent advances in their fields of special interest.

The uses of timber in defence stores were varied and often demanded materials of the highest quality. The Timber Section was concerned mainly with the selection and supply of Australian timbers as alternatives to those called for in British specifications, and also with the study of the resistance of local timbers to decay and attack by pests and the best methods of preserving them from such attacks. Investigation of the kiln seasoning of timbers for rifle furniture, and of casein cements for use in the construction of wooden aircraft, were among the earliest activities of this section.

The introduction of attack by means of poison gases, liquids and smokes during the war of 1914-18 led to chemical defence being accorded a high place in the work of the laboratories. Inquiry into essential chemical industries and progress in other countries in developing new chemical agents and protective devices for chemical warfare was the concern of the Chemical Defence Section.

Another important activity of the laboratories was the inspection of munitions which preceded their acceptance by the Services. When the munition factories were being reorganised in the early twenties the army argued its right, according to long-standing precedent, to inspect munitions, contending that since their quality was a matter of life and death for the soldier, this right belonged to it as the user organisation. A compromise was reached by which inspection was controlled within the Munitions Supply organisation by an officer, Lieut-Colonel Gipps,[5] nominated by the army. This system worked well between the wars, but in 1939, by an agreement between the two departments, it reverted to the army, where it remained until the end of the war.

By arrangement with the British War Office, drawings and specifications of any approved new weapon were forwarded to the Defence Department in Australia, where they were recorded and filed in the Equipment Office. Experts of this office, in association with those of the Munitions Supply Laboratories, then examined the drawings and specifications and if necessary amended them to suit Australian conditions. At a later stage, when the army, having approved and sealed the drawings and specifications, placed an order for a particular weapon, the Inspection Branch provided itself with the necessary inspection gauges, either by importing them from England or by having them manufactured locally. Well-equipped proof ranges at Port Wakefield, South Australia, and Williamstown, Victoria, where small arms, guns and ammunition could be subjected to exacting firing tests, were placed under the control of the Inspection Branch. Substantially the same arrangements for inspection have persisted to the time of writing. A fuller account of the different phases of inspection will be given in appropriate chapters.

[5] Lt-Col H. B. L. Gipps, Chief Inspector of Munitions, then Inspector-General of Munitions, 1920-32, 1939-45. Regular soldier; of Melbourne; b. Forbes, NSW, 6 Aug 1880.

When, in 1923, the year after the establishment of the laboratories and the Inspection Branch, the important principle was affirmed at the Imperial Conference in London that each Dominion should be responsible for its own local defence and at the same time should cooperate in the defence of the Empire as a whole, the Commonwealth Government, confident of the organisation then being built up, had no hesitation in accepting it. The principle was, in fact, implicit in all Australian plans for procuring munitions. The expenditure during the early twenties of about £3,000,000 on the four government munition factories and the laboratories, an amount far greater than that of all the other Dominions put together for the same period, was a concrete expression of the Government's recognition of the obligations it had assumed.

In describing the work of the Munitions Supply Laboratories the word standards has been mentioned in two different senses: firstly, and at some length, in reference to accurate measurements to ensure interchangeability and mating of mass-produced components; secondly, but only very briefly, in reference to the quality of manufactured goods and their fitness for specific purposes. In this latter sense the term may imply methods of sampling, testing and using different materials; or it may define codes of technical practice, including safety codes, or may fix a limited range of sizes of a product for normal use to avoid wasteful diversity. The process of attaining uniformity of the last kind is often referred to as standardisation. These implications of the word are usually more fully covered by the phrase "standard specification". In the early stages of their activities, it will be recalled, the government munition factories confined themselves to British practice and to War Office specifications; very little was done to introduce the advantages of standardisation to commercial industry.

Since, in the last analysis, Australia's defensive strength depended on both the government nucleus factories and commercial industry, it will, in this chapter, be necessary to examine briefly the impact of scientific and technical trends on commercial industry. Two illustrations will make clear the critical importance of uniformity or standardisation.

Before 1841 all screw threads were cut laboriously by hand to no particular shape, angle or pitch, so that no two threads were interchangeable. In that year Sir Joseph Whitworth laid down designs for standard threads, which made possible a great advance in interchangeability. Whitworth's standard threads were adopted in Britain and in other countries of the Empire, but the great productive machine of the United States was based on an entirely different system of screw threads, which later made interchange of equipment between the two major Allied nations impossible. Trivial differences between British and American screw threads were estimated in the United States to have cost the Allies more than $1,000,000,000 during the second world war.

A more familiar example is provided by the failure of the Australian States to standardise the gauges of their railways; a failure which exacted a heavy toll on the country's transport system in the war of 1939-45 when

it became necessary to move large bodies of troops and equipment to Queensland from the southern States.

The great value of standardisation in mass production, with its consequent increase in efficiency and economy in costs, was another lesson that emerged from industrial experience in the war of 1914-18. This lesson was not lost on Australian engineers. By 1919 the growing appreciation of the burden to importers, manufacturers and consumers alike, occasioned in some instances by the multiplicity of engineering standards and in others by their complete absence, led engineers to urge the need for national standardisation. Foremost among them was Mr Lightfoot,[6] Chief Executive Officer of the Commonwealth Institute of Science and Industry. He pointed out, for example, that merchants found it necessary to stock incandescent electric lamps for twenty different voltages throughout the Commonwealth; that the various State railway systems used rails of different dimensions and different kinds of steel—that there were in fact four different specifications for rails, which varied only in minor respects that could not be regarded as significant except that they represented a waste of effort.[7]

Lightfoot, having earlier gained some knowledge and experience of the British Engineering Standards Committee,[8] publicly urged that a similar body should be formed in Australia. Later in 1919 he met representatives of the recently formed Institution of Engineers (Australia) and discussed his scheme. After some further negotiations, the Institution of Engineers, early in 1922, called a conference of interested bodies, including the Institute of Science and Industry (later the Council for Scientific and Industrial Research), the Australian Chemical Institute (later the Royal Australian Chemical Institute), and the Australasian Institute of Mining and Metallurgy, at which unanimous resolutions were passed in favour of setting up a standards association. These resolutions were conveyed to and approved by the Commonwealth Government, and with the active support of the Munitions Supply organisation, the Australian Commonwealth Engineering Standards Association was formed. The first meeting of its governing body, the Main Committee under the chairmanship of Mr Knibbs,[9] was held on 2nd November 1922.

Some five years later the association assisted in launching a new body, the Australian Commonwealth Association of Simplified Practice, which aimed not so much at formulating standard specifications as at simplifying processes of manufacture by agreement among manufacturers. Its purpose, more fully stated, was to reduce the effort expended on manufacturing many types of goods serving almost identical purposes. Its aim was to use the method successfully applied in the United States of persuading

[6] G. Lightfoot, MA. Chief Executive Officer of Institute of Science and Industry, 1920-26; former Secretary and Member of Council of CSIR. Of Melbourne; b. Newcastle-on-Tyne, Eng, 3 May 1877.

[7] G. Lightfoot, *Engineering Standardisation*, Institute of Science and Industry Pamphlet No. 2 (1919).

[8] Later called the British Standards Institution, and said to have been the first body of its kind anywhere in the world.

[9] Sir George Knibbs, CMG. Commonwealth Statistician, 1906-21; Member of Royal Commission on Food Supplies and Trade and Industry, 1914-15; Director of Bureau of Science and Industry, 1921-26. Of Melbourne; b. Sydney, 13 Jun 1858. Died 30 Mar 1929.

manufacturers to agree to eliminate types of goods in low demand and to concentrate on producing a range of goods known to meet best the needs of the consumer. The work of the two bodies overlapped so much that in 1929 they were merged to form the Standards Association of Australia, a body similar to the British Standards Institution. By dropping the word "engineering" from its title the scope of the association's activities was widened to cover practically every field of industry. Mr Julius,[1] a leading consulting engineer who for sixteen years served the association as its chairman, gave inspired leadership in framing its policy and building it up during the formative years. He was ably supported by Mr Hebblewhite,[2] first full-time officer of the association and later its director.

Since the degree of organisation implicit in standardisation of industrial practices and provision of specifications is an integral part of technological processes and is vitally necessary for their efficient operation, the formation of the Standards Association of Australia for the preparation and promulgation of such codes and practices was an important milestone in the country's industrial history. The importance to defence of cooperation between the standards bodies of the different Empire countries was fully recognised at the Imperial Conferences of 1926 and 1930, at both of which a considerable fillip was given to the extension and coordination of standards work. Close cooperation with the British Standards Institution was of the greatest value in developing the Australian movement, which soon gained the confidence of both industry and the Government.

The Standards Association was an independent body supported by contributions from industry and governments. As the greatest contributor, the Commonwealth maintained close relations with it through the Council for Scientific and Industrial Research, which acted as the liaison body. The association was governed by a council and its technical work was supervised by "industry committees", under whose direction the work of preparing specifications was carried out by sectional committees. All committees were honorary and of a representative character, nominations of experts being invited from organisations interested in the particular specifications. On the 500 committees, representing about 5,000 members, commercial interests were always strongly but never predominantly represented.

The task of coordinating standards within the States of the Australian Commonwealth was an unusually arduous one, for several reasons. At Federation the Commonwealth assumed certain spheres of responsibility; other spheres, such as factory control, electricity supply, building construction, highways, railways, ports and harbours, water supply and sewerage, and other technical services, came within the authority of the six States. The difficulty of coordinating State activities in most of these spheres was accentuated by the great distances separating the main indus-

[1] Sir George Julius, BSc, BE. Consulting engineer. Chairman CSIR, 1926-45; inventor of automatic totalisator. Of Sydney; b. Norwich, Eng, 29 Apr 1873. Died 28 Jun 1946.

[2] W. R. Hebblewhite, OBE; BE. Lecturer, RM College, Duntroon, 1913-23; General Secretary, Chief Executive Officer and later Director and Chairman Standards Assoc of Aust 1924-1953. B. Strathfield, NSW. 31 Dec 1885.

trial centres of Australia, most of which were situated in the capital cities. This geographical isolation accentuated a tendency for industrial practices to develop along divergent lines, an extreme manifestation of which has already been noted in the railway gauges of the different States. The large amount of work done by the Standards Association in preventing endless repetitions of such mistakes was an important factor in industrial development.

Standardisation has been described as concentration upon what is best in current practice, and as such tends to raise the general level of a country's industrial achievement by improving the quality and design of all kinds of manufacture. Since in time of war the entire industrial resources of a nation, over and above those required to provide the barest needs of its civilian population, were pressed into its defence, the work of a standards organisation assumed considerable significance. Much of the association's success was due to a policy, in line with that of the British Standards Institution, of securing the cooperation and consent of the three parties concerned with the formulation and application of standard specifications. A standard specification represented a pooling of the wisdom and experience of the manufacturer, of the user of the goods, and of the standards organisation itself. Its task was "(to borrow a phrase from diplomatic history) to publish open agreements openly arrived at".[4] With its facilities for securing information from other countries the standards organisation was able to keep manufacturers in touch with the latest advances resulting from research and experience. A specification drawn up as a result of this kind of collaboration and bringing to the notice of engineers and industrial executives the best in current practice, was likely to be adopted more readily than might otherwise be the case.

When war broke out in 1914, shortages of such things as dyestuffs and optical instruments, of whose manufacture Germany had a near monopoly, brought home to the British Government the need for providing more scientific help to industry; the result was the establishment in 1917 of the Department of Scientific and Industrial Research. During a visit to Britain about this time, the Australian Prime Minister, Mr Hughes,[5] heard much about this new department and became imbued with the idea that a similar organisation was needed in Australia. With this in mind he set up an Advisory Council of Science and Industry, a temporary body intended to prepare the way for a more permanent one to be known as the Institute of Science and Industry. "The objective," said Hughes, "was to apply to the pastoral, agricultural, mining and manufacturing industries the resources of science in such a way as to more effectively develop our great heritage." A detailed scheme for the permanent body, drafted by

[4] *Fifty Years of British Standards, 1901-1951,* published by the British Standards Institution, London (1951).

[5] Rt Hon W. M. Hughes, CH; KC. MLA NSW 1894-1901; MHR 1901-52; Minister for External Affairs 1904, 1921-23, 1937-39; Attorney-General 1908-9, 1910-13, 1914-21, 1939-40; Prime Minister 1915-23; Minister for Health and for Repatriation 1934-35, 1936-37, in charge of Territories 1937-38, for the Navy 1940-41. B. Wales, 25 Sep 1864. Died 28 Oct 1952.

Professor David Masson[6] and his colleagues on the Advisory Council,[7] was approved and published by the council in July 1917 under Hughes' chairmanship. At the critical moment political support failed. It was not until three years later, after persistent and powerful advocacy by Masson, that an Act was passed setting up the new body.[8]

In creating this organisation the Government was in step with Canada, South Africa and New Zealand, all of which had recognised that defence strength and industrial development necessitated scientific research on a scale often beyond the capacity of private enterprise.[9] Under the guidance of its director,[1] Sir George Knibbs, the Institute of Science and Industry, following up the work of the former Advisory Council, laid the foundation for a number of important investigations, such as the manufacture of paper from Australian hardwood and the eradication of prickly pear, which were later brought to completion by its successor, the Council for Scientific and Industrial Research. That the earlier bodies did not achieve more was in a large measure due to the fact that the Government's financial support was grudging and inadequate.

Masson, whose leadership did so much to help the formation of the Institute of Science and Industry, was one of the outstanding figures in Australian science in the early years of the present century. His years of greatest activity coincided roughly with those in which Federation began to exert a marked influence on the organisation of science, and he figured prominently in the formation of several professional associations and institutions of a national character.[2]

Convinced of the wisdom of gathering into one fold the separate groups of chemists dispersed throughout the Commonwealth, Masson took the lead in the formation of the Australian Chemical Institute. Not until some years after its formation in 1917 and its incorporation under the *New South Wales Companies Act* in 1923 was the institute able to achieve standards for admission to membership comparable with those of the Royal Institute of Chemistry of Great Britain, but when it did reach this level, in the early thirties, it successfully petitioned for a Royal Charter, thus becoming the first scientific society to be so incorporated since Federation. Despite the difficulties inherent in operating an organisation with branches in each State, the institute steadily raised the status of chemists so that when war came, by which time the membership

[6] Sir David Orme Masson, KBE; FRS, MA, DSc, LL.D. Prof of Chemistry, Univ Melbourne, 1886-1923; President of Aust National Research Council 1922-26. B. London 13 Jan 1858. Died 10 Aug 1937.

[7] Prof J. Douglas Stewart, Mr G. D. Delprat, Mr F. M. Gellatly, Mr W. Russell Grimwade, Prof Thomas Lyle, Mr E. A. Mann, Prof R. D. Watt, Mr C. S. Nathan, Dr A. E. V. Richardson, and Mr A. B. Piddington.

[8] *Institute of Science and Industry Act, 1920.*

[9] England established the Department of Scientific and Industrial Research in 1917; Canada the National Research Council in Aug 1917; South Africa the Scientific and Technical Advisory Board in Feb 1917; New Zealand the Dept of Scientific and Industrial Research in 1926. A memorandum, "Recent Developments in the Organisation of National Industrial Research Institutions", prepared by Mr Lightfoot under the auspices of the Executive Committee of the Advisory Council, gives a detailed picture of contemporary development in these countries.

[1] Mr F. M. Gellatly, the first director, died not long after his appointment.

[2] The first national scientific organisation was the Australasian Association for the Advancement of Science, founded in 1887.

had risen to about 2,000, it was able to provide considerable assistance in the mobilisation of scientific manpower. The only professional organisation with a larger membership was the Institution of Engineers, Australia, founded in 1919 by the amalgamation of a number of State and smaller Federal bodies[3] and incorporated by Royal Charter in 1938. With branches in every State and a membership of over 6,000, the Institution of Engineers was to prove a tower of strength to the Director of Scientific Manpower in those anxious years of the second world war when the resources of manpower were strained to the very limit.

Another, much smaller, body was the Australian Branch of the Institute of Physics, formed about the same time (1924), mainly through the efforts of Professor Ross.[4] No institution of comparable membership did more to help government munitions organisations over the years 1939-45.

Towards the end of 1918 conferences were held in London, Paris and Brussels to discuss ways of resuming international scientific activities which had of necessity been suspended during the war. As a result of these deliberations a body known as the International Research Council was formed. Australia was one of the sixteen countries invited to join the council, a condition of membership being that it must possess a national academy or a similar body capable of representing it internationally. Since Australia possessed no such body, her scientific leaders began moves which in 1919 brought into being the Australian National Research Council. Fully representative of science (eighteen different branches were included) and commanding the support of scientific leaders in Australia,[5] the council soon built its membership up to 100. It not only represented Australia at international scientific congresses but helped to awaken political interest in the cause of scientific research at a time when, owing to inadequate financial support, the Institute of Science and Industry was beginning to falter.

Consequently, in 1926 the institute underwent a radical reorganisation, changing both its name and the scope of its activities, to become the Council for Scientific and Industrial Research (C.S.I.R.). The Prime Minister, Mr Bruce,[6] having in mind the country's need for more help from science, asked Sir George Julius to become the organisation's first chairman and to select his own colleagues on the executive. Julius chose

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[3] The Electrical Association of Australia, Institute of Local Govt Engineers of A/sia, Engineering Association of NSW, Melbourne and Sydney University Engineering Societies, Q'land, SA, Tas and WA Institutes of Engineers, and the Northern Engineering Institute of NSW.

[4] A. D. Ross, CBE; MA, DSc. Hon Secretary for Aust and NZ of Institute of Physics, London, 1924-43; Prof of Physics, Univ of WA, 1912-51. B. Glasgow, Scotland, 7 Sep 1883.

[5] This is evidenced by the fact that in the first decade of its activities eight Fellows of the Royal Society were among its chief supporters: Sir David Masson, Sir Edgeworth David, Sir Thomas Lyle, Sir Douglas Mawson, Prof W. E. Agar, Prof F. Wood-Jones, Dr R. J. Tillyard, Sir Charles Martin. See Prof A. P. Elkin's account of the history of the formation and activities of the ANRC in the *Australian Journal of Science*, Vol 16, p. 203 (1954).

[6] Rt Hon Viscount Bruce, CH, MC; FRS. (Lt Worcestershire Regt 1915, Capt Royal Fusiliers 1916-17.) MHR 1919-29, 1931-33; Treasurer 1921-23; Prime Minister and Minister for External Affairs 1923-29; High Commissioner for Aust in London 1933-45. Of Melbourne; b. Melbourne, 15 Apr 1883.

Dr Rivett[7] as Deputy Chairman and Chief Executive Officer, and Mr Newbigin[8] as the third member. In Bruce science had a powerful supporter who was prepared to do more than pay lip service: he made sure that the C.S.I.R. was granted enough money to enable it to become firmly established. Through his active interest the Government also established, about this time, the Commonwealth Solar Observatory on Mount Stromlo, near Canberra.

The C.S.I.R., which was to serve primary and secondary industry in much the same way as the Munitions Supply Laboratories served the government defence factories, was endowed with extremely wide powers, not only for the initiation and carrying out of scientific research but also for the training of research workers and the making of grants in aid of scientific research. For the latter a sum of £100,000, known as the Science and Industry Endowment Fund, was set aside. The C.S.I.R. was also empowered to undertake the testing and standardisation of scientific apparatus, and the establishment of a bureau of information concerning scientific and technical matters. Two features of its constitution, based upon ideas put forward by the Australian National Research Council,[1] were, in the opinion of many scientists, likely to be conducive to its success: first, its administration did not come under the Public Service Board; and secondly, it was free from direct political control, though it was responsible to its Minister. Both features were deemed essential to secure the degree of freedom needed for the sound development of a national scientific body. Though later events were to fully justify these views, the organisation was not, as we shall see later, immune to political attack.

Having established its headquarters in Melbourne, the C.S.I.R. set about organising its work into a number of divisions, which within a few years embraced:

Division of Animal Nutrition, formed in 1927.
Division of Animal Health, formed in 1930. In 1935 the two amalgamated to become the Division of Animal Health and Nutrition. Some years later this division was split into the Divisions of Biochemistry and General Nutrition and of Animal Health.
Division of Soils, formed in 1927.
Division of Forest Products, formed in 1928.
Division of Food Preservation, formed as a section in 1931; became Division of Food Preservation and Transport in 1940.
Division of Economic Botany, formed in 1927; became Division of Plant Industry in 1930.
Division of Economic Entomology, formed in 1926.

All this early developmental work was made easier by reason of the fact that the council did not have to budget from year to year but was

[7] Sir David Rivett, KCMG; FRS, MA, DSc (Melb). Prof of Chemistry, Univ of Melbourne, 1924-27; Deputy Chairman and Chief Executive Officer, CSIR, 1927-45, Chairman 1946-49, Chairman CSIRO Advisory Council 1950. Of Melbourne; b. Port Esperance, Tas, 4 Dec 1885.

[8] W. J. Newbigin, a leading engineering executive. His firm was the representative in Australia of Vickers Ltd, British shipbuilders and armament manufacturers. He was suceeded on the executive by Dr A. E. V. Richardson.

[1] "Science and Security", *Australian Journal of Science*, Vol 2, p. 147 (1949).

able to plan its work for several years ahead on the basis of an initial grant of £500,000. No effort was made to centralise the organisation; laboratories and research stations were set up in different parts of the Commonwealth—wherever was most appropriate for the work concerned. Some laboratories were placed within the grounds of universities, with the idea—not publicised at the time—that if the council were to fail the universities at least would be able to recover something from the wreck. The council did not fail; its scientists and those of the universities profited greatly from the contacts and exchange of ideas thus made possible. Its scientists also cooperated with those of State departments (especially of agriculture) and with other government and scientific bodies.

The council was fortunate in starting its life with a strong and well-balanced executive. Julius, a leading engineer and a practical man of affairs who could quickly assess a proposed course of action and form a shrewd estimate of the amount of money needed to carry it out, served as a foil to Rivett, a scientist whose knowledge of and insistence on the conditions essential to the pursuit of free scientific inquiry did much to attract to the council's staff men of high scientific calibre. Preoccupied as it was in its earliest years with the problems of primary industry, the C.S.I.R. needed a man thoroughly versed in agricultural science. In Dr Richardson,[2] who joined the executive when Mr Newbigin died in 1927, it found a man admirably fitted to hold this key position. The council was no less fortunate in the choice of its first secretary, Mr Lightfoot, a skilful administrator with a training in engineering, science and law, whose earlier experience as Chief Executive Officer of the temporary Advisory Council enabled him to guide the C.S.I.R. successfully in public service procedure.

Within a few years the C.S.I.R. had achieved some remarkable successes: in cooperation with the Commonwealth Prickly Pear Board and the Governments of New South Wales and Queensland, it played an important part in freeing more than 60,000,000 acres of valuable land from prickly pear; with assistance from the universities and departments of agriculture it did much to bring under control diseases of cattle and sheep which had previously cost the country considerable sums; it also laid the foundations for what, during the war years, became a flourishing paper industry based on hardwood pulp. All this was brought about by a policy of giving its scientists freedom to tackle the long-range problems of primary industry in the ways they thought best. The emphasis was first and foremost on fundamental research, in fields of endeavour likely to yield results of practical value to primary industries.

The C.S.I.R. did not rely only on government grants for support; it was helped by a number of private benefactors who made bequests for the establishment of research institutes. For example, the F. D. McMaster Animal Health Laboratory was erected in the grounds of the University of Sydney as a result of a gift to the Commonwealth Government by

[2] A. E. V. Richardson, CMG; MA, DSc, BScAgric. Prof of Agriculture and Director of Waite Agricultural Research Institute, Univ of Adelaide, 1924-37; Chief Executive Officer, CSIR, 1938-49. B. Adelaide, 12 Sep 1883. Died 5 Dec 1949.

Sir Frederick McMaster,[3] and a new laboratory for soil studies was built at the Waite Institute, Adelaide, from money given by Mr Harold Darling.

Since, in the first years of its existence, the council concentrated almost exclusively on the problems of primary industry, it may be questioned whether this phase of its activities had any relevance to defence. If only because it did so much to ensure the nation's wellbeing by setting its primary industry on a more scientific basis, thus improving the yields of crops, wool and meat, the answer is clearly Yes, because in the latter part of the war of 1939-45 one of the greatest challenges the Commonwealth had to meet was to increase its production of food under most adverse circumstances.

The work of the Division of Forest Products, begun in 1929, was to enable a great extension in the use of Australian timbers, and their wider application for defence purposes.

Again, few could have foreseen the valuable dividends that the fundamental work of the Radio Research Board (supported jointly by the C.S.I.R., the Postmaster-General's Department and the universities) on problems of radio propagation would pay during the coming war.

So far the council's activities had been concentrated on primary industry. In 1936, however, the Commonwealth Government decided that the time had arrived to extend scientific and technical assistance to secondary industry. Under the Act by which it was constituted the council was entrusted with the responsibility of "testing and standardisation of scientific apparatus and the carrying out of scientific investigations connected with standardisation of apparatus, materials and machinery". It was along these lines that the Government first sought to help Australian industry undertake the manufacture of aero engines and motor cars.

In point of fact most of the facilities now considered desirable had already been instituted at the Munitions Supply Laboratories, but these were intended primarily for defence needs, although they were available to and were used by commercial industry occasionally. The resources of science were now required by industry on a much wider field than could be catered for by these laboratories without encroachment upon their essential purpose of serving the production of munitions and defence requirements generally.

The Government's present move was influenced by the belief that if Australia were to acquire a larger population fairly rapidly, it could support it better by expanding secondary industry; as mechanisation on farms increased, fewer people were likely to be needed in primary industry. The reduction of imports as a means of redressing an unfavourable trade balance brought about by lowered returns from the sale of primary production overseas, would be welcome. There was too, the argument that in circumstances such as the trade depression of 1929-32 the presence of a well-developed and diversified secondary industry would have helped

[3] Sir Frederick McMaster. Pastoralist; of Cassilis, NSW. Made numerous gifts of money and stock to public institutions; honorary life member of Royal Agricultural Society of England. B. 9 Jul 1873. Died 28 Nov 1954.

to cushion the effect on the Australian economy. Perhaps, however, the most important consideration was the conviction that in the event of war Australia would have to be, as nearly as possible, independent of oversea supplies of essential manufactured goods.

With a few notable exceptions, most large Australian industrial concerns failed to maintain research laboratories; what were called research laboratories often did little more than exercise process control. Even such a large undertaking as the steel industry made few attempts to engage in any research worthy of the name of pure science. Firms which were branches of, or had close working relations with large oversea organisations tended to rely on the parent firm for research, which in the early stages of their development was understandable. Many industries found it cheaper to buy the results of oversea research, a proceeding which, as experience was to show, was not without risk in time of war. Smaller firms were simply unable to afford the maintenance of research laboratories, and where large groups of smaller undertakings, such as foundries, tanneries or furniture factories, had problems in common there was a strong case for providing some kind of help to them either through research associations or through a body such as the C.S.I.R.

In announcing the decision to go ahead with this plan to help industry, the Prime Minister, Mr Lyons,[4] stated on 7th July 1936 that a committee to be known as the Secondary Industries Research and Testing Committee had been formed to go into the whole matter and to prepare a report to guide the Government in giving effect to its policy. The committee, consisting of twenty leading scientists, engineers and industrialists, made an exhaustive survey of the needs of the manufacturing industries in Australia and issued its report in February 1937.

One immediate result of this report was that important extensions were made in the range of the activities of the C.S.I.R. In 1938 plans were drawn up for the erection of three laboratories that were to add greatly to the country's technological strength: the National Standards Laboratory, the Aeronautics Engine and Testing Research Laboratory, and the Division of Industrial Chemistry. An account of some of the important wartime contributions of these laboratories to the country's defence will be given in appropriate chapters.

By 1939 the C.S.I.R. was the dominant force in Australian science. In the number of highly-trained scientists and in the diversity of the research projects undertaken, no other organisation approached it. Until the advent of the C.S.I.R. the universities had been the principal centres for scientific research and scholarship. State departments of agriculture and mines were preoccupied with applied science—with solving the day-to-day problems of their respective industries. When Australian universities were founded they were planned on a liberal scale, considering the stage of the country's development, but once the early enthusiasm had waned they did not receive

[4] Rt Hon J. A. Lyons, CH. MHA Tas 1909-29; Premier 1923-28. MHR 1929-39; Postmaster-General and Minister for Works and Railways 1929-31; Treasurer 1932-35; Prime Minister 1932-39. B. Stanley, Tas, 15 Sep 1879. Died 7 Apr 1939.

the financial support needed to develop strong post-graduate schools of scientific research. They therefore concentrated on the training of professional people: doctors, lawyers, engineers, agricultural experts and teachers. Little money was left over for research.

In the early days lack of financial support was not the only obstacle in the way of the development of scientific research in the universities. Science can develop only slowly, if at all, in isolation; to do his best work a scientist needs the stimulus of contact with other scientific minds. That scientific research grew so slowly in Australia, from the small beginning made towards the end of the nineteenth century, can in large measure be attributed to this factor. Australian scientists laboured under conditions of isolation peculiarly intensified by geography: not only is the continent distant from world centres of science, but the capital cities, where the Australian universities were situated, are themselves widely separated from one another. Most of the early scientific work in Australia was concerned with natural history and geology. That any work at all was done in the fields of physical science was due to the enthusiasm of a few lone workers.

The charter of the C.S.I.R. clearly implied that the Australian universities were, at the time of its establishment, unable to meet the country's needs for science graduates; further, that the amount of research carried out in universities, especially in the field of biology, was inadequate to cope with the special nature of many of the problems with which Australia's agricultural and pastoral industries were being confronted. Lacking strong post-graduate schools of chemical engineering and other technological faculties, the universities were almost equally powerless to assist in the solution of the technical problems associated with the birth and development of secondary industries.

Two courses of action were open to the council: to put its weight almost wholly behind the universities as its charter empowered it to do, building up research units within the universities and doing all that was possible to assist them in training scientists; or to do what in fact it did: set up teams of research workers in separate institutes, leaving the universities for the most part to struggle on as best they could, and at the same time hoping that they would be able to turn out enough trained scientists to meet the council's needs. The latter course of action was the more likely to produce fairly quickly the positive results—the conquest of pests and of plant and animal diseases—that would win the confidence of governments voting money for the C.S.I.R. Subsequent events have gone a long way towards justifying what might have seemed a sacrifice of principles to expediency. The universities were not overlooked altogether: the council often helped them by making small grants for the purchase of scientific equipment and for the assistance of post-graduate students; in this way it encouraged research in the universities to an increasing degree as the war approached.

Despite all their handicaps, university science departments continued to develop, here and there making useful contributions to fundamental knowledge, until by the time war broke out most of them were in a

position, as will be seen in the sequel, to provide considerable scientific assistance in the defence of Australia.

During the ten years following the establishment of the Munitions Supply Board, the government munitions factories underwent a slow but steady expansion. The Explosives Factory at Maribyrnong was extended for the production of high explosives; hitherto only propellants had been manufactured. The Small Arms Ammunition Factory, which had been leased from the Colonial Ammunition Company in 1921, was purchased outright in 1927 and rebuilt. Rolling mills, more extensive and more modern than those possessed by any commercial factory, were installed for the fabrication of non-ferrous alloys used in making cartridge cases, detonators and fuses. At the Lithgow Small Arms Factory the capacity of the tool-room was doubled in order to make the tools and gauges for the 18-pounder gun, and manufacture was extended from rifles to Vickers machine-guns. Perhaps the most important development of this period was the completion of the Ordnance Factory with its facilities for producing quick-firing field artillery. A factory was also set up for production of the steel high-explosive shells of gun ammunition, and this included the only hydraulic shell-forging presses in Australia.

Most of the machinery for these factories had been bought from the United Kingdom after the 1914-18 war. Jensen, alive to the possibility of acquiring large quantities of munitions plant at this time, was able to obtain the support of Senator Pearce,[5] who took the matter up with the British Minister for Munitions, Lord Inverforth. Little progress was made in negotiations until Mr Winston Churchill, in that period Secretary of State for War and later for the Dominions, took the matter up, and characteristically prompt action followed.

For several years after it arrived in Australia this machinery lay idle awaiting the construction of factories to house it. When at last it was set up, in 1923, the Government possessed in its munitions factories equipment and manufacturing facilities unrivalled in Australia.

When the economic depression spread over the Commonwealth and orders from the Services were drastically reduced, the Government had on its hands considerable manufacturing capacity (£3,000,000 worth) which it could not afford to see lying idle. Unlimited stockpiling of munitions was not a satisfactory way out of the dilemma because of their liability to deterioration and obsolescence. The only way to keep the government factories going was to allow them to accept orders from commercial industry. So that they would not be competing with local manufacturers, who were also then struggling hard against the effects of the depression, it was decided that the factories should confine themselves to making goods hitherto imported. Contracts were chosen for goods whose manufacture would help to preserve the technical skills which had

[5] Rt Hon Sir George Pearce, KCVO. Senator 1901-38; Min for Defence 1908-9, 1910-13, 1914-21, 1932-34, for Home and Territories 1921-26, External Affrs and i/c Territories 1934-37. Chairman Board of Business Admin 1939-48. Of Perth, WA, and Melbourne; b. Mount Barker, SA, 14 Jan 1870. Died 24 Jun 1952.

been so hardly gained, and at the same time to prevent the spread of unemployment. Thus it came about that the Small Arms Factory at Lithgow began manufacturing combs and cutters for sheep-shearing machines, golf irons, refrigerator parts, gear blanks and even patent handcuffs; it also made large numbers of Western Electric sound projectors for theatres all over Australia; the Ammunition Factory at Footscray rolled brass and nickel sheets and strip for industry, and made thousands of lipstick containers. Instead of T.N.T. and cordite, the Explosives Factory made paints and lacquers, and chemicals such as oil of mirbane (nitrobenzene), which was used in shoe polish and other commercial products.

The manufacture of cordite was not stopped altogether. An order from New Zealand kept the factory going on a reduced scale. This was fortunate, since "discontinuous out-turn" in an explosives factory greatly increased the risk of fire and explosion; there was a greater liability to accident at the time when production was about to stop or when it was just starting up again.

There was little work for the Ordnance Factory to do since the 18-pounder gun on which it had embarked was now considered obsolete, but its opportunity to help commercial industry arose in the early thirties after the Scullin Government placed a tariff on motor-car spare parts. Up to this time the automotive industry in Australia had been concerned with little more than body building, an activity which originated during the war of 1914-18 when the Commonwealth Government imposed restrictions on the importation of motor bodies. The industry expanded considerably during the twenties with the establishment of works by the Ford Motor Company of Canada Ltd, at Geelong, Victoria, and by the General Motors Corporation at Woodville, South Australia. Introduction of the new tariff restrictions was to a large extent responsible for bringing about the second stage in the growth of the industry: the manufacture of spare parts.

Engineers sent out from America by General Motors to investigate the position reported that the only industry equipped with complete facilities for manufacturing certain car parts, including measuring and gauging facilities and those for testing materials, was the Ordnance Factory at Maribyrnong and the supporting Supply Laboratories.

Probably the most important job undertaken was the mass production of motor-car axles, which had not up to then been made in Australia to the exacting specifications of American manufacturers. An essential requirement was high-grade alloy steel. Fortunately, at that time the Broken Hill Proprietary Company Ltd (B.H.P.) had recently developed the technique for producing this type of steel. The joint effort of B.H.P. and the Ordnance Factory was highly successful in developing this phase of motor-car manufacture, and large numbers of axles of various sizes were made during the depression. This, therefore, represented a distinct advance and set a new standard in Australian manufacture.

Other motor-car components made by the Ordnance Factory during the same period were the universal joint, the shock absorber, and springs. A great deal of experience was obtained in the factory and in the laboratories

on these projects, and at a later stage when the factory resumed its normal munition-manufacturing activities, the technical information acquired in the manufacture of parts for motor cars was passed on to commercial industry.

Progress in the automotive industry had an important influence on Australian engineering industry as a whole, since it involved the introduction of modern machinery and the production of steel and other metal parts by casting, forging, stamping, and machining to close tolerances—tolerances similar to those required for the weapons of war.

With the passing of the economic depression the munitions factories slowly returned to their normal activities, and even underwent a small expansion. The Explosives Factory was extended to manufacture naval cordite, and much of the Small Arms Factory at Lithgow was rebuilt. In the country at large secondary industry made a rapid recovery—much more so than did primary industry. This rapid recovery, together with the signs that Europe was entering on a period of considerable political uneasiness, caused munitions authorities to pay more attention than hitherto to the problem of mobilising commercial industry to meet the emergency of war.

CHAPTER 2

MOBILISING INDUSTRY FOR WAR

IT will be recalled that an essential part of the general plan for enabling Australia to arm her own forces was that nucleus government factories should work out the techniques of making munitions and instruct commercial industry in them so that in times of emergency the industrial resources of the country could be fully exploited for defence. In developing this plan it was natural that attention should at first have been focused on the government laboratories and factories. Australian secondary industry in the early twenties was too immature to have profited much from any attempt to develop the second phase of the plan. Though the terms of reference of the Munitions Supply Board contained no clause defining its responsibility for the second phase, it was generally understood by its members that in time of war its function would be to mobilise commercial industry. To do this successfully would entail much preparation beforehand, and it was with this in mind that the board in 1926 arranged for Mr Breen[1] to undertake a Commonwealth-wide survey of the potentialities of commercial industry as a producer of munitions. This was an undertaking of considerable magnitude. To make ammunition for the 18-pounder gun, for example, would require a score of chemical raw materials and more than twice as many chemical intermediates for the various explosives used in it, together with textiles, rubber, paper and half a dozen or more metals and alloys, and machines for fabricating them. The survey was complicated—as all such surveys are—by the continual change in the industrial situation, which made accumulated information soon out of date. Industry, especially that associated with the fabrication of metals, was growing rapidly but lopsidedly, lacked standards, and was not as yet highly organised. Before the survey had been completed, Breen accepted a position as Assistant Secretary of the C.S.I.R. The vacancy thus created in the office of the Munitions Supply Board was not filled immediately, and during the economic depression the appointment was allowed to lapse indefinitely.

Efforts along these lines were not revived until March 1933 when, after some prodding from the British Government and representations from the three Services in Australia, the Council of Defence[2] decided to carry out a recommendation made at two successive Imperial Conferences (in 1926 and 1930) to set up a Principal Supply Officers' Committee. The Australian Principal Supply Officers' Committee (P.S.O.C.), following the pattern of the corresponding British organisation, consisted of supply

[1] H. P. Breen, CBE. Asst Secretary CSIR 1936-39, Dept of Supply 1940-41, Dept of Munitions 1941-45; Director of Industrial Development 1945-49; Secretary Dept of Supply 1949-51, Dept of Defence Production since 1951. Of Melbourne; b. Richmond, Vic, 30 Apr 1893.

[2] This was a statutory body created under the *Defence Act* to advise the Federal Cabinet on questions of defence policy. The council, of which the Prime Minister was chairman, consisted of a selected group of Ministers, the three Chiefs of Staff and the Secretary of the Defence Department.

members of the Military, Navy and Air Boards, the Financial Secretary and the Assistant Secretary of the Department of Defence, and the Controller-General of Munitions Supply, who was chairman. The committee's function was to advise the Council of Defence on measures designed to ensure that both government factories and commercial industry would be able to provide munitions on a scale adequate for the country's defence. The magnitude of this scale was, at the direction of the Defence Committee, calculated on the assumption that the armed forces should be prepared to repel "light raids" by an enemy.

For the purpose of carrying out its work the Australian committee, still following the pattern of the British organisation, set up eight Supply Committees, essentially sub-committees, whose activities were coordinated by a Supply Board composed of their respective chairmen. In order to avoid confusion with the Munitions Supply Board, the coordinating body (which became in effect the executive body of the P.S.O.C.) was later renamed the Defence Resources Board; the committees then became known as Resources Committees. Their responsibilities covered: 1. arms and armament; 2. general and marine engineering;[3] 4. hardware, general stores and clothing; 5. electrical equipment, scientific and optical instruments; 6. aircraft, aero engines, motor transport; 7. victualling stores; 8. fuel oil and petroleum products generally.[4]

At a meeting on 5th September 1935 the Defence Committee directed that the P.S.O.C. should plan to have its investigations at an advanced stage by the end of 1939, since it was considered highly probable that war would break out in Europe, and possibly in the Far East, about that time.

No one who was familiar with the problem of national defence doubted that in the event of war the larger part of the burden of arming the nation would fall on commercial industry. The question was how and when commercial industry should be mobilised for this purpose. This first became a big issue in 1936. In April of that year Lieut-Colonel Beavis,[5] Military Liaison Officer on the staff of the High Commissioner in London, was appointed full-time Chairman of the Defence Resources Board. As the Australian representative on the British P.S.O.C., Beavis had had every opportunity to observe the way in which this committee interpreted its responsibilities, and could therefore be expected to give some lead to its Australian counterpart.

Beavis returned to Australia from England with a keen sense of the urgency of the international situation and of the peril Australia would face if war broke out in the Far East. The government munitions factories were,

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[3] The committees were numbered to correspond with those in Britain; No. 3 committee was never formed here.

[4] The chairmen of the various committees were: 1. Col G. E. Manchester (Army); 2. Eng Cdr A. C. W. Mears (Navy); 4. Maj E. J. Milford (Army); 5. Sqn Ldr E. C. Wackett (Air Force); 6. Gp Capt E. Harrison (Air Force); 7. Paymaster Cdr H. M. Ramsay (Navy); 8. Cmdre R. J. O. Otway-Ruthven (Navy).

[5] Maj-Gen L. E. Beavis, CB, CBE, DSO. (1st AIF: comd 53 Bty AFA.) Director of Ordnance Services AIF in Middle East, 1940-42; Master-General of the Ordnance, AMF, 1942-46; Aust High Commissioner in Pakistan 1952-54. Regular soldier; of Bathurst, NSW; b. Bathurst, 25 Jan 1895.

at this time, still struggling from the effects of the economic depression; and commercial industry, because of its general lack of experience in the techniques of mass-production engineering and its inability to undertake the high-precision work needed for making munitions, was unprepared for the demands that war would make on it. The contrast with highly-industrialised Britain offered a challenge which to a man of Beavis's active and enthusiastic temperament could not be denied.

The Defence Resources Board had not long been in existence when it became evident that there was a sharp difference of opinion between Leighton and Beavis about the timing of the effort to organise commercial industry. One theme that constantly recurred in Beavis's reports was: better the thorough organisation of commercial industry before war than improvisation after war breaks out. This was the lesson of the disastrous shortage of munitions in Britain during the 1914-18 war. Beavis wanted to see the work of organising commercial industry begun immediately, and in this he had the strong support of the Services, especially the army and the air force many of whose members felt that the Munitions Supply Board was not doing as much as it should in this direction. However, although the Defence Committee had stated that the country should be ready for war by 1939, the money to carry out the necessary preparations was not forthcoming; the prevailing climate of public and political opinion favoured disarmament rather than preparation for war, and only meagre funds were allotted to defence. The degree of expansion possible was therefore confined within very narrow limits.

In order to extend the field of munitions production to commercial industry it was necessary among other things to place "educational orders". Leighton believed that the best value for the limited funds at his disposal could be obtained by first bringing the government munitions factories up to concert pitch. Consequently he resisted, with all the means in his power, any attempt to divert these funds from the government factories. As Controller-General of Munitions Supply and Chairman of the P.S.O.C. the means at his disposal were considerable. There was no room for two strong opposing policies, and in April 1937 Beavis was recalled to the army.

Other changes followed: in August 1938 the P.S.O.C. was reorganised on a sounder basis with Major Rowe[6] as its chief executive officer;[7] the Defence Resources Board and its committees were abolished and replaced by an Executive Panel comprising a number of full-time officers of whom

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[6] Col G. C. Rowe. (1st AIF: 1 Siege Bty.) Munitions representative in London 1919-25; Executive Officer, Defence Supply Planning Cttee, 1939-40; Controller, Gun Ammunition Production, 1940-46. B. Castlemaine, Vic, 31 Jul 1894. Died Jun 1949.

[7] The new PSOC consisted of: N. K. S. Brodribb, Inspector-General of Works and Supplies, Chairman; Members: Capt G. P. Thomson, for Naval Board; Maj-Gen O. F. Phillips, for Military Board; Air Cmdre W. H. Anderson, for Air Board; A. S. V. Smith, for the Secretariat; J. K. Jensen, for Munitions Supply Board and Contract Board; Major G. C. Rowe, Executive Officer for matters of administration; C. J. W. Gillan, Executive Officer for matters of finance; W. Howie, Secretary.

Commander Herbert[8] was the leader; sub-committees were created to deal with medical supplies, food, fuel oil and lubricants.[9]

In November 1937 Leighton retired (in accordance with Public Service regulations), and was succeeded as Controller-General of Munitions Supply by Mr Brodribb.[1]

The tempo of much of this reorganisation was doubtless hastened by the Imperial Conference of 1937, not so much (as Butlin points out[2]) by any specific recommendations from the conference itself as from the insight it gave the Australian delegates into the alarming extent to which the European situation had deteriorated. Unequivocal confirmation of these impressions was provided by the Munich Agreement in September 1938—the first of a series of shocks that galvanised the Government into something more than paper planning to mobilise the nation's industrial resources.

The reorganised P.S.O.C., on completing a survey of commercial industry as a source of ammunition components, reported that the "factories of the Munitions Supply Board could be relied upon to supply about 10 per cent of the components under review (that is, the amount of gun ammunition of all natures and sizes estimated as being necessary for the army to repel 'light raids') and that capacity to make the remainder must somehow be created".[3] The P.S.O.C's preoccupation with ammunition arose from two considerations: manufacture of ammunition constituted a large proportion of any munition program; and owing to its high rate of wastage it was essential to have the manufacture of ammunition well organised before war broke out if critical shortages in the early stages were to be avoided. As a means of creating the necessary facilities the P.S.O.C. recommended that twenty-four special factories, to be known as armament annexes, should be constructed in close association with various State instrumentalities (mainly the railway departments) and prominent industrial organisations, which would operate them on behalf of the Government. The intention of this proposal was to avoid the growth of a large private munitions industry and to avoid building huge factories that would be useless after the war. An annexe, it was suggested, might be built at government expense on land belonging to a company but leased to the Government; or the operating organisation might provide the land and the building, and even, in some cases, the plant and equipment. The more extensively existing facilities could be used the better.

Convinced of the wisdom of cultivating the goodwill and of securing the cooperation of industry, the P.S.O.C. recommended the formation of

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[8] Engr Capt D. P. Herbert, BSc, BE; RAN. (HMAS's *Australia* 1915, *Yarra* 1916.) Naval Engineer Officer, Australia House, London, 1934-38; Senior Technical Investigator, Defence Supply Planning Cttee, 1938-40; Principal Naval Overseer, SA, 1941-45. Of Melbourne; b. Sydney, 11 Nov 1888.

[9] The chairmen of these committees were: Medical, Dental and Veterinary Sub-committee, Maj-Gen R. M. Downes; Oil Fuel Sub-committee, Capt J. A. Collins, RAN; Foodstuffs Sub-committee, C. Massey.

[1] N. K. S. Brodribb, CBE. Manager of various government factories since 1915; Chief Chemical Engineer, Dept of Defence, 1921-37; Controller-General of Munitions Supply 1937-40, 1945-51; Assistant Director-General of Munitions 1940-45. B. Kew, Vic, 27 Dec 1885.

[2] S. J. Butlin, *War Economy, 1939-42*, in this series.

[3] "Interim Report on the Investigation of Industry as a Source of Ammunition Components", 9 Sep 1937.

a panel of leading industrialists to advise the Government. This suggestion was promptly acted upon, and on 10th March 1938 the Prime Minister announced that a body to be known as the Advisory Panel on Industrial Organisation had been created under the chairmanship of Mr Essington Lewis,[4] Chief General Manager of the Broken Hill Proprietary Company Ltd, to study the measures necessary for mobilising commercial industry. Other members of the panel were Sir Colin Fraser,[5] Sir Alexander Stewart,[6] Mr Eady[7] and Mr Kneeshaw.[8] Within seven days of its appointment the panel made a report on the problems and proposals that had been submitted to it.

The panel had been informed that the two main objectives of the Munitions Supply Board were to build up in the shortest possible time sufficient stocks to provide six months' reserves of ammunition for the army and the air force, and to create sufficient manufacturing capacity to cope with the great expenditure of ammunition likely to occur in war. As a heavy responsibility for building up stocks clearly fell on the existing government factories, the panel recommended that no time should be lost in forcing these factories up to their full capacity.

With regard to the second objective, the way was not so clear. In the opinion of the panel it was not practicable to undertake the manufacture of shells and bombs in existing commercial engineering shops with any degree of efficiency. It was true, it said, that there existed throughout Australia's engineering shops a large number of general-purpose machine tools which in time of emergency could be commandeered, reassembled and re-erected fairly quickly in annexe factories, but this could not be done without seriously dislocating normal industry. More tools, gauges, jigs, fixtures and machine tools would be essential.

The panel therefore strongly supported the P.S.O.C. in recommending that stocks of machine tools and raw materials should be built up and that the twenty-four annexes to existing industrial organisations should be established forthwith. Management of the annexes on behalf of the Government by the organisations with which they were associated would, the panel believed, enable them to be fully manned and efficiently supervised and controlled. For its part the Government saw in the scheme a means by which it could keep some check on the costs of production and exercise some measure of control over profits. Both these themes, which are outside the scope of the present discussion, are treated at length by Professor

[4] Essington Lewis, CH. Managing Director, BHP, 1926-38, Chief General Manager 1938-50; Director-General of Munitions 1940-45 and Director-General of Aircraft Production 1942-45. Of Melbourne; b. Burra, SA, 13 Jan 1881.

[5] Sir Colin Fraser, MSc. Mining geologist and engineer and company director. Director of Materials Supply, Dept of Munitions, 1940-44. Of Melbourne; b. Coromandel, NZ, 14 May 1875. Died 11 Mar 1944.

[6] Sir Alexander Stewart. Consulting engineer and company director. Chairman, Vic Board of Area Management, Dept of Munitions, 1939-45. Of Melbourne; b. Aberdeen, Scotland, 1877. Died 6 May 1956.

[7] M. T. W. Eady. President, Vic Chamber of Manufactures 1935-37, Treasurer from 1943. The Representative of Industry on various Manpower Boards and Committees during the war. Company director; of Melbourne; b. Sydney. Died 8 Dec 1947.

[8] Hon F. P. Kneeshaw, OBE. (Served 1st AIF.) MLC NSW 1933-49; Chairman, Aust Shipbuilding Board, 1941-43. Company director; of Sydney; b. Canterbury, NZ, 6 Aug 1883. Died 3 Feb 1955.

Butlin. The intention was that each annexe should be a "whole purpose" establishment: one devoted to the manufacture of components for one particular kind of ammunition, such as 18-pounder shell bodies, brass fuses, primers or 3-inch mortar bombs. The panel was greatly concerned to find that in the Commonwealth there was only one explosives and filling factory (that at Maribyrnong) and that all gun ammunition made in decentralised factories had to be transported to this centre. It suggested that serious consideration should immediately be given to the possibility of building another explosives and filling factory outside Victoria.

With the ready cooperation of the industries concerned several annexes were in an advanced state of construction by April 1939. Contracts for twenty-three annexes had been let before war broke out and by June 1940 18 were ready to go into production. While they were being built the Government provided funds for laying in stocks of machine tools and for stockpiling some strategic raw materials, such as nickel and aluminium from Canada, copper from South Africa, sulphur and tool-steel from the United States, and sodium nitrate from Chile. At the same time a survey of manpower was initiated and further efforts were made to explore the country's industrial productive capacity.

These last steps were the outcome of the passing in June 1939 of the *Supply and Development Act,* which dealt with ". . . the Supply of Munitions and the Survey and the Registration of the Resources of Australia", and which led to the setting up of the Department of Supply and Development with Mr Casey[9] as Minister in Charge.

In addition to taking over the functions of the Munitions Supply Board, the Contracts Board and the P.S.O.C. (which had been renamed the Defence Supply Planning Committee), the Department of Supply and Development assumed responsibility for the assembly and manufacture of aircraft, for which purpose it set up an Aircraft Construction Branch under the managership of Mr Clapp.[1] The new department's responsibilities for the mobilisation of commercial industry were far more explicitly defined than those of the Munitions Supply Board had been. The department was given power to

(i) make arrangements for the establishment or extension of industries for the purposes of defence;

(ii) acquire, maintain and dispose of stocks of goods in connection with defence;

(iii) arrange for the coordination of:

(*a*) surveys of Australian industrial capacity and the preparation of plans to ensure the effective operation of Australian industry in time of war, including plans for the decentralisation of secondary industries and particularly those relating to defence; and

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[9] Rt Hon R. G. Casey, CH, DSO, MC. (Served 1st AIF.) MHR 1931-40 and since 1949; Treasurer 1935-39; Minister for Supply and Development 1939-40, 1949-50, for National Development 1950-51, for Works and Housing 1949-51, for External Affairs since 1951. Aust Minister to USA 1940-42. UK Minister in Middle East 1942-43. Governor of Bengal 1944-46. B. Brisbane 29 Aug 1890.

[1] Sir Harold Clapp, KBE. Chairman, Vic Railway Commissioners, 1920-39; Chairman, Aircraft Production Commission, 1940-42; Director-General Land Transport 1942-44. B. Melbourne, 7 May 1875. Died 21 Oct 1952.

(*b*) the investigation and development of Australian sources of supply of goods which are necessary for the economic security of the Commonwealth in time of war, and in particular, the investigation and development of additional oil resources, the production of power alcohol from sugar or other vegetable crops, and the production of oil from coal or shale.

(iv) ascertain costs and control and limit profits in relation to the production of munitions.

In other words, the Government now had the power to institute control of commodities, build up stocks of materials, rationalise industry, develop alternative local sources of raw materials, and control profits on munitions. When war broke out on 3rd September 1939 there was a well-organised government munitions supply authority with some preliminary provision for enlisting the powerful support of commercial industry in the manufacture of a limited range of armaments, chiefly components for ammunition. Even so the real task of arming the nation had scarcely begun.

The administrative staff of the government munitions organisations then numbered only 18 (it was to rise to more than 6,000 by 1943) and the number of employees was 5,055 (this figure was to rise to more than 54,000). The developmental program launched in 1938, for which the Government had set apart £3,000,000, brought about an increase in the scale and scope of the productive capacity of its munitions factories. By September 1939 another £3,000,000 had been provided. All factories were placed on two long shifts, or three when practicable, though in organising the second and third shifts severe limitations were imposed by the shortage of supervisory staffs and skilled tradesmen. Fortunately it was appreciated in the early days of the war that there would be serious shortages of skilled tradesmen, especially in the metal industries, and steps had been taken to set up a Commonwealth training scheme.

In those days of September 1939 (said Jensen later, in an address to the Institute of Industrial Management) none of us, not even informed people in England, could anticipate what lay ahead, but we of the Munitions Branch, as things appeared to us, could not deny some small feeling of satisfaction with our planning and development of the past years; now we should see whether our work had been worth while. It had been a hard time, that period of retrenchment, disbelief, disarmament and depression, but the support we had received from successive governments, despite adverse finances, had been encouraging, and even in the worst year of all we had actually increased our employment.

One of the first pieces of legislation passed after the declaration of war was the *National Security Act*,[2] which greatly extended the Government's powers to control the individual and the country's resources. Among other things it provided for taking possession or control on behalf of the Commonwealth of any property or undertaking, or the acquisition on behalf of the Commonwealth of any property other than land; for requiring any person to disclose any information in his possession on any prescribed matter. The Act gave the Government power to issue regulations which would enable it to effect the total mobilisation of the country's resources.

[2] Passed by the Federal Parliament on 9 Sep 1939.

However the need to exercise these controls fully did not occur for some time.

In the first few months of the war a curious situation arose whereby some government munitions factories, having then been brought up to their full capacity, were faced with the possibility of not having sufficient orders to keep them going. The very efficiency with which they had been brought to full capacity seemed more likely to prove a source of embarrassment than an advantage. Only a week after war broke out intimations from the Services were that when the orders for small arms ammunition then under execution had been completed, nothing further would be required for some time. Had this state of affairs continued, wholesale dismissal of men from the factory would have been inevitable. So acute did this situation become that consideration was given to the question whether it would not be wise to invite the United Kingdom to place orders for munitions (mainly ammunition) in Australia. This step was deferred, however, until the needs of the Services could be more definitely ascertained. The Government temporarily eased the crisis by allotting an additional sum of money to the factories.

For a time the government factories did produce a surplus of some items, principally small arms ammunition and empty shell bodies, and the opportunity was taken of accepting orders from Britain, New Zealand, India and the Netherlands East Indies. Not the least of the gains arising from this policy of export was the confidence it engendered in the quality of the products of the government factories.

Early in 1940 Jensen began to press for more orders from the Services, because he knew that unless there was sufficient notice of requirements it would be impossible promptly to meet demands for new kinds of intricate weapons. In mass production there is an inevitable delay in beginning manufacture, owing to the necessity for "tooling up". For example, it took about six months to prepare for the mass production of a shell, twelve months for a rifle or machine-gun, and for an anti-aircraft gun something like two years. This time lag, inherent in the mass-production technique, was not always fully appreciated by members of the Services other than those responsible for provision of equipment, or by the public. Several years might be needed to bring the whole of the country's industrial resources into war production.

The period of uncertainty and waiting, sometimes referred to as the "phoney war", did not last long. It was merely the lull before the storm. When at last "the slowly gathered, long pent-up fury of the storm broke", as it did in May 1940, developments followed quickly enough. Great losses of equipment were sustained by the British forces during their withdrawal from France. Of the 2,794 guns shipped to France with the British Expeditionary Force only 322 were brought back to England; of 109,000 tons of ammunition only 32,303 tons. A British armoured division and several armoured brigades fought in France, but only 9 cruiser tanks and 13 light tanks returned to England. The desperate position in which Britain found herself after the fall of France has been graphically described

by Mr Churchill: "Our armies at home were known to be almost unarmed except for rifles. There were in fact hardly 500 field guns of any sort and hardly 200 medium or heavy tanks in the whole country. Months must pass before our factories could make good even the munitions lost at Dunkirk."[4] Australia was thus presented with an entirely new prospect. It was perfectly clear that Britain would need all her energy and resources to replace her losses and to prepare to meet a large-scale air offensive, and perhaps even invasion of her shores. Her needs were so urgent that the Australian Government sent rifles and ammunition from its own reserves, and continued to fulfil orders for other munitions. Late in 1940 Britain received from Australia 30,000 rifles and 6 heavy anti-aircraft guns; 44 guns were later sent to the Middle East. By June 1941 Australia had supplied 100,000,000 rounds of small-arms ammunition, 36,000 filled and 146,000 unfilled mortar bombs. British historians have commented: "The 30,000 Australian rifles take on a new importance when it is recalled that total production in the United Kingdom in 1940 was only 81,000, that the [British] Army was drilling with dummies and that no .303-inch weapons arrived from North America until 1942."[3]

Though Australia could still count on being able to import some of her requirements of raw materials and machine tools from the United States, there was no telling how long she could continue to do so. Clearly an effort on a scale far exceeding that of any previously attempted, or even imagined, was now called for.

The needs of the new situation were forcefully described by the Prime Minister, Mr Menzies:[5]

> We must take every power so to order, so to command and direct the factories of Australia, those who operate and those who work in the factories in Australia, that we may in the shortest possible time produce the greatest possible supplies of armaments, ammunition, mechanical transport and all those things which the modern army requires if it is to fight with success.

This declaration heralded the final administrative steps towards mobilising the whole of the country's resources for the production of munitions; munitions would now be produced not only in government factories and in the twenty-five annexes built up to this time, but wherever practicable in commercial industries throughout the length and breadth of the land. It was to be "total war" on the industrial front.

Menzies' first intention had been to appoint a commission of three to direct the new drive for munitions, but he did not adhere to this plan. Instead he called Mr Essington Lewis to Canberra and on 21st May 1940 asked him to accept the office of Director-General of Munitions. The War

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[4] Winston Churchill, *Second World War*, Vol II (1949): *Their Finest Hour*, p. 1.

[3] H. Duncan Hall and C. C. Wrigley, *Studies of Overseas Supply* (1956) in the War Production Series of the British *History of the Second World War*.

[5] Rt Hon R. G. Menzies, CH. MHR since 1934; Attorney-General 1935-39; Treasurer 1939-40; Prime Minister and Minister for Defence Coordination 1939-41; Prime Minister since 1949. B. Jeparit, Vic, 20 Dec 1894.

Cabinet immediately approved this move and on 22nd May the Prime Minister publicly announced the new appointment. The entire organisation for producing munitions was to be overhauled, detached in an administrative sense from the Department of Supply and Development, and given the title of Department of Munitions, with responsibility direct to the Prime Minister (who assumed the office of Minister for Munitions). Leaders of industry with experience in the methods of mass production engineering were to be called in to enable the fullest possible use to be made of commercial industry. Over them all was to be placed the Director-General of Munitions entrusted with the widest powers—perhaps the most responsible position of its kind ever allotted to an Australian.

In order to give Mr Essington Lewis the greatest possible degree of authority, subject only to the policy and approval of the War Cabinet and to ministerial direction from myself, there will be established a Department of Munitions, with myself as Minister and Mr Lewis as Director-General. Mr Lewis will have access to the War Cabinet, in the same way as the Chiefs of Staff, on matters which relate to his work.

This new Department of Munitions will deal with all ordnance, small arms, explosives and ammunition, together with such ancillary matters as gas masks, and will have a supervisory jurisdiction over aircraft supply. It will also include related materials.

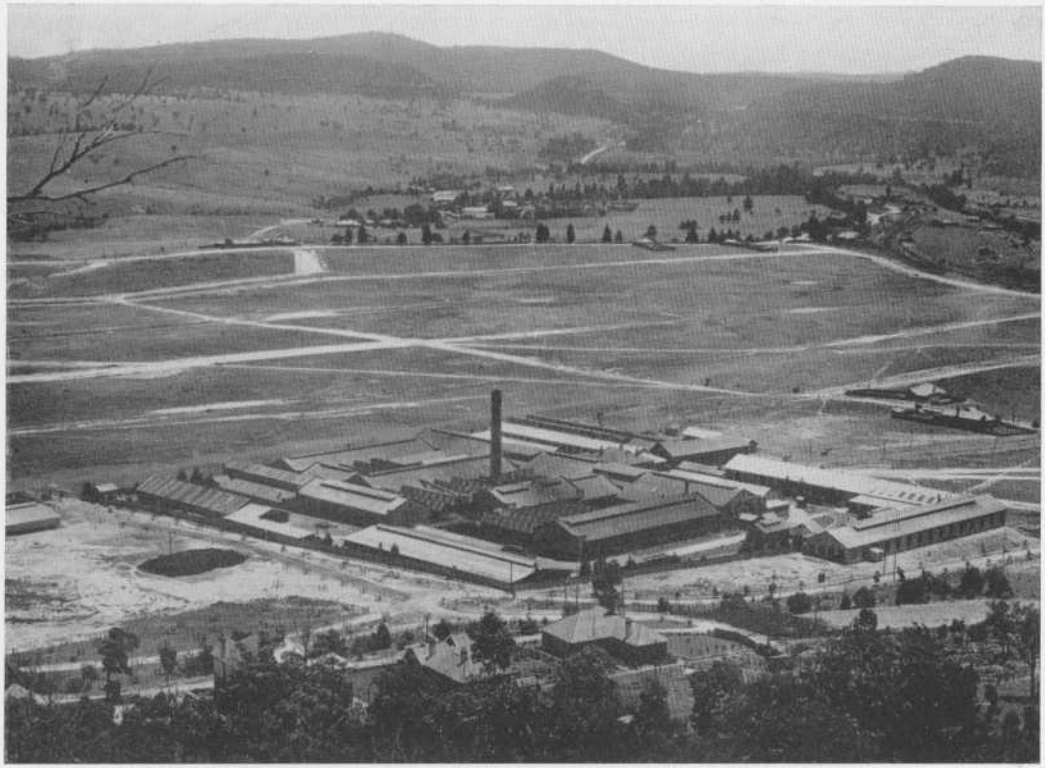
The Director-General will be given a complete power of delegating authority. He will be a member of the Defence Committee. Through his Minister he will have the right of initiating matters for consideration by the War Cabinet. The new department will, as far as possible, use the existing machinery of the Supply Department, including the Contracts Board.

Instead of securing specific approvals from time to time, one of the earliest duties of the new Director-General will be to confer with the other members of the Defence Committee in an endeavour to formulate a series of objectives which it is desirable to achieve during some prescribed period. If these objectives are then approved by the War Cabinet, the mandate to the Director-General will be a perfectly simple one. It will be: Go ahead in your own way and achieve these objectives in the shortest possible time.

We will take power by regulation, to the extent to which it does not already exist, to requisition all private resources of plant and equipment. The Director-General will be authorised to make purchases direct without tenders or circumlocution. A standing order will be issued by the Government that no factory may provide for any new tooling-up without authority. . . . The Director-General will not be limited by Public Service regulations or otherwise in regard to the employment of personnel.[6]

The man chosen for this extraordinary post—virtually an industrial dictator — matched it with equally extraordinary capacities. As Chief General Manager of the Broken Hill Proprietary Company Ltd Lewis had for many years been the guiding force in the development of Australia's vigorous and efficient steel industry, and had come to be accepted as the country's outstanding production engineer and industrial executive. In his capacities of Chairman of the Advisory Panel on Industrial Organisation, and as business consultant to the Department of Defence, he had already advised the Government on the production of munitions. Up till

[6] From Mr Menzies' broadcast to the nation on 16 Jun 1940.



Lithgow Small Arms Factory—the nursery of mass production in Australia.



A. E. Leighton.



Sir John Jensen.

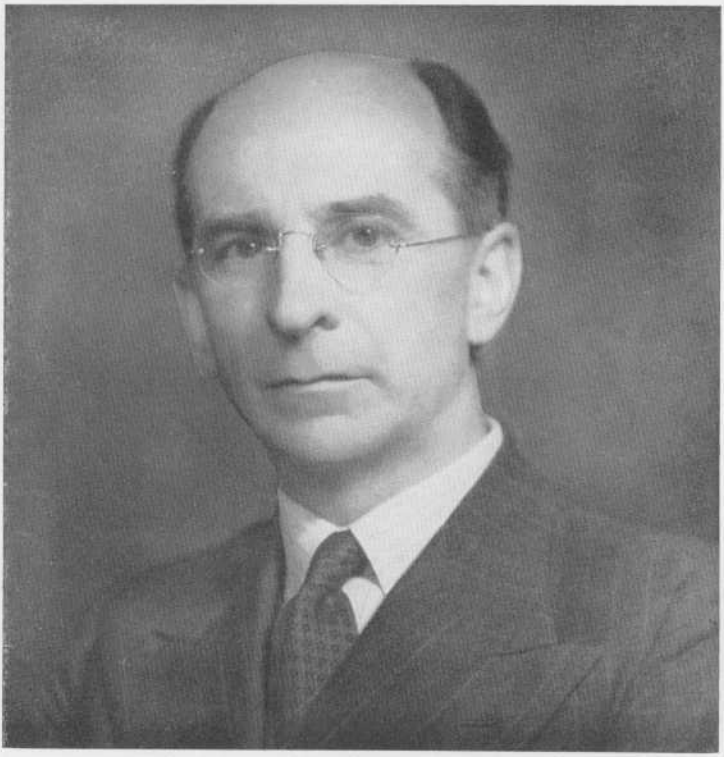


Essington Lewis.



Some of Australia's Munitions Leaders.

(*Hanna in* Argus, *Melbourne*)



Sir David Rivett.



Sir Eric Ashby. (*Belfast Telegraph*)

this time he was almost unknown to the ordinary citizen. No other Australian was so well fitted for the position, and there was complete agreement in Parliament between Government and Opposition to his appointment.

Lewis had a vast capacity for work. A man of tireless energy and wholehearted devotion to his job, he was capable of inspiring the loyalty and cooperation of those with whom he worked. In the course of his duties as Director-General of Munitions he would make flying visits (in the Silver City, an aircraft owned jointly by the B.H.P. and Broken Hill silver-lead mining interests) to as many as six engineering and chemical works in one day. That such visits were not mere cursory inspections was borne out by the flood of instructions that would be issued on his return to headquarters. Lewis had a flair for picking the right men as his lieutenants, and having chosen them he gave them his full trust. He expected others to work as hard as, and to be as efficient as, himself. He had a knack of getting things done, whatever the obstacles.

To assist him in his new task Lewis brought a team from the iron and steel organisation who, like Lewis himself, continued throughout the war as salaried officers of B.H.P. or its subsidiaries.[7] No remuneration was sought from the Commonwealth, the companies concerned regarding this arrangement as part of their contribution to winning the war.[8]

At a historic meeting held on 14th June 1940 a plan was adopted for the new munitions organisation that was to endure practically unaltered until the end of the war. The plan, essentially the one used for the British Ministry of Munitions in the 1914-18 war, adapted to the conditions prevailing in Australia, had been drawn up by Jensen and submitted first to the Department of Defence in March 1939.[9] The time was then not ripe for it, and it was shelved. No one had a more intimate knowledge of the pre-war government munitions organisation than this administrator, who had been associated with it for the greater part of his working life. Jensen's great abilities had up to this point been to some extent overlooked. At committee meetings he rarely spoke, but when he did so his contribution was always to the point. He preferred to be a power behind the scenes, and in fact became increasingly so as the munitions industry expanded and developed.

This time Jensen's plan was presented neither to the Minister for Defence nor to the War Cabinet, but was adopted by Lewis entirely on his own responsibility. An essential feature of the plan was the setting up of a number of directorates, each of which was placed under a prominent industrialist or administrator. Centralised control was effected through a Board

[7] The team consisted of: Messrs J. L. Jenkins (personal secretary), J. McShane (technical assistant), and F. T. Merrett (chief engineering assistant).

[8] Neville Wills, *Iron and Steel in Australia* (1955).

[9] At that time Jensen was Controller of Munitions Supply, a member of the Munitions Supply Board and Chairman of the Defence Contract Board.

of Directors, which met regularly in Melbourne under the chairmanship of the Director-General. The Board of Directors consisted of:

Assistant Director-General	N. K. S. Brodribb
Aircraft	H. W. Clapp
Ordnance	L. J. Hartnett[10]
Gun Ammunition	W. J. Smith[1]
Machine Tools and Gauges	Col F. G. Thorpe[2]
Materials Supply	Sir Colin Fraser
Finance	E. V. Nixon[3]
Labour	J. B. Chifley[4]
Explosives Supply	T. Donaldson[5]
Secretary, Dept of Munitions	J. B. Brigden[6]
Assistant Secretary, Dept of Munitions	J. K. Jensen[7]

Fraser was a leader of the non-ferrous metals industry group; Clapp, Chairman of the Victorian Railway Commissioners; Hartnett, Smith and Donaldson were directors of three of the biggest companies in Australia, concerned respectively with motor cars, glass and chemicals; Thorpe was director of the leading machine-tool company; Nixon was a leading public accountant; and Chifley, who had been a Minister for Defence in the Scullin Government, was now a newspaper proprietor in Bathurst, New South Wales. Directors who were executives of large commercial organisations gave their services to the Department of Munitions in an honorary capacity.

Since it could not be expected that such men, however eminent in their own fields, would be able to walk into the immense department that had just been created and take over the planning of large-scale manufacture of products entirely unfamiliar to them, it was arranged that each should have as second-in-command a controller, who would be a man trained either in the administrative procedure of the government munitions organisation or else have had some experience in the technique of manufacturing

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[10] L. J. Hartnett, CBE. (RNAS and RAF 1917-19.) Managing Director, General Motors-Holden's Ltd, 1934-47; Director Ordnance Production, Dept of Munitions, 1940-45. B. Woking, Eng, 26 May 1898.

[1] W. J. Smith, CBE. Managing Director, Aust Consolidated Industries. Director of Gun Ammunition, Dept of Munitions, 1940-42. B. London, 28 May 1882.

[2] Sir Fred Thorpe, MC, ED. (Served 1st AIF.) Chief Engineer, Southern Cd, 1939-40. Director, McPhersons Ltd and Assoc Machine Tools Aust Pty Ltd, 1939-53. Director Machine Tools and Gauges, Dept of Munitions, 1940-45. B. Macorna, Vic, 25 Dec 1893.

[3] Sir Edwin Nixon, CMG. Chartered accountant and company director. Director of Finance, Dept of Munitions, 1940-45. B. Jersey, Channel Is, 31 Mar 1876. Died 19 Aug 1955.

[4] Rt Hon J. B. Chifley. MHR 1928-31, 1940-51. Minister for Defence 1931; Treasurer 1941-49; Minister for Post-War Reconstruction 1942-45; Prime Minister 1945-49. Director of Labour, Dept of Munitions, 1940. B. Bathurst, NSW, 22 Sep 1885. Died 12 Jun 1951. Chifley, who became seriously ill in Aug 1940, did not resume after his election some months later. He was succeeded by E. J. Kavanagh, a Conciliation Commissioner.

[5] T. Donaldson. Technical consultant to ICIANZ Ltd and alternate member of the board from 1938; Director of Explosives Supply, Dept of Munitions, 1940-44. B. Stevenston, Scotland, 14 May 1877. Died 24 Jan 1951.

[6] J. B. Brigden, MA. (Served 1st AIF.) Prof of Economics, Univ of Tasmania, 1924-29; Director, Qld Bureau of Economics, later of Industry and State Statistician, 1930-1938; Sec, Dept of Supply 1939-41 and of Munitions 1940-41; Economic Counsellor to Aust Minister in Washington 1942-47. B. Maldon, Vic, 20 Jul 1887. Died 12 Oct 1950.

[7] This list of directorates was added to from time to time. They fell into three principal divisions, and as finally organised these were:
Administration: Finance; Labour; Technical Practice; Production Orders and Statistics.
Control and Provision: Material Supply and Machine Tools.
Production: Gun Ammunition; Ordnance; Armoured Fighting Vehicles; Radio and Signal Supplies; Explosives; Locomotives and Rolling Stock; and finally, Small Craft.

appropriate to the particular directorate. The controllers of the directorates set up in June 1940 were as follows:

Ordnance	F. S. Daley[8]
Gun Ammunition	G. C. Rowe
Machine Tools and Gauges	T. A. Witten[9]
Materials Supply	H. C. Green[1]
Finance	C. J. W. Gillan[2]
Labour	R. J. Murphy[3]
Explosives and Filling	A. A. Topp[4]
Administration	J. K. Jensen

Coordination of the directorates was effected principally through the Controller of Administration but another arrangement contributing largely to this was the monthly meeting presided over by Lewis at which each director read a progress report of the activities under his charge. These conferences were an important feature of Lewis's administrative technique in so far as they kept all directors in touch with policy, served as a method of arriving at important decisions, and kept everyone up to the mark.

After hearing all there was to be said (recalled Jensen) Mr Lewis would sum up and advance his own ideas, after which there was opportunity for further comment, assent or dissent, and then he would announce his decision. His personal secretary, having noted the salient features of the discussion and the decisions, would circulate memoranda of these within a few hours to all the interests concerned, and consequently there was always a full understanding of what was said and decided.

The meetings seem to have left a deep impression on all who attended them. Years afterwards Jensen commented:

To my mind they were, every one of them, unique occasions in many respects. . . . I cannot recollect a case of ill-feeling or ill-will arising, or anything that could not be adjusted after discussion with good will and toleration; there was no quarrelling, no "hanging back in the traces" after an adverse decision—and that is something to say when it is considered that the majority were men of forceful personality accustomed to having their commands received without question.

The next three years were to be no royal progress but a story of almost interminable shortages and difficulties. There were also spectacular successes, and directors' meetings would be enlivened when

lumbering noises would be heard at the door, men would be panting and we would guess that Mr Hartnett had broken another record. With pardonable pride of

[8] F. S. Daley, BMechE. Assistant Manager, Ordnance Factories, Maribyrnong, to 1931; Staff Engineer, Production Engineer, Technical Adviser to General Motors-Holden's to 1939; Controller, Deputy Director, Director, Ordnance Production; General Technical Manager, Kelvinator Aust Ltd. B. Bendigo, Vic, 1 Nov 1892.

[9] T. A. Witten. (Served RN, first world war.) Engineer, Thompsons Ltd, to 1939; Controller, then Director, Machine Tools and Gauges, 1940-45. Of Melbourne; b. Barraba, NSW, 31 Jul 1892.

[1] H. C. Green. (Served 1st AIF.) Asst C'wealth Statistician 1937-38; Asst Secretary Dept of Supply 1939; Director and Controller of Materials Supply, Asst Secretary, Dept of Munitions, 1940-45; Director and Gen Manager, Sidney Cooke Ltd, since 1945. Of Melbourne; b. Shepparton, Vic, 2 May 1893.

[2] C. J. W. Gillan. Accountant, Army HQ, Melb. 1939; Chief Accountant, Dept of Munitions, 1941; Asst Secretary 1941-45; Asst Secretary, Dept of Supply and Development, 1948-49. Of Melbourne; b. Camberwell, Vic, 11 Jan 1887.

[3] R. J. Murphy, OBE. (Served 1st AIF.) Former Chief Clerk Defence Dept, Controller Labour, Munitions Dept, Asst Secretary, Dept Labour and National Service; Secretary, Dept of Transport, 1943-48. Industrial relations consultant. Of Melbourne; b. Yengarie, Qld, 16 Dec 1882.

[4] A. A. Topp, OBE. Works Manager, Explosives Factory, 1926, Manager 1928; Controller, Explosives Supplies, 1940-44, Director 1944-48; General Manager, Explosives Factory, Melbourne, 1948-52. Of Melbourne; b. South Yarra, Vic, 2 Jan 1886. Died 29 May 1952.

achievement something never before made in the country would be carried in; the table would be creaking under, say, a 3-inch trench mortar as Hartnett expounded the merits of a set-up for mass production and the quality of the product. Particularly and justifiably was he proud of the work done by his Optical Munitions Panel.

It was recognised from the outset that while the general planning and coordination of the munitions program could be efficiently carried out at Melbourne headquarters, the functions of management throughout Australia could not be directed from one point. Accordingly Boards of Area Management,[5] charged with the direction of the manufacture of munitions by commercial industry, were set up in the capital cities of each State. Boards consisting of prominent industrialists and representatives of organised labour were assisted by area controllers, who were responsible for providing technical assistance to manufacturers, as well as for arranging for the supply of materials, machine tools and gauges, and skilled labour. The secretary of each Board of Area Management was a regular public servant responsible for administration and the keeping of accounts, thus leaving members of the board free to direct technical and business operations. The intention was that the secretary, who was nominated by the Public Service Board, should keep the industrialists on the narrow path of public service procedure. The original chairmen and secretaries of the boards were:

NSW	Sir Philip Goldfinch[6]	J. W. J. Byrne[7]
Vic	Sir Alexander Stewart	A. A. Tregear[8]
Qld	Col D. E. Evans[9]	D. Sutherland[1]
SA	Hon F. T. Perry, MLC[2]	S. Lillywhite[3]
WA	R. O. Law[4]	A. A. C. Ramm[5]
Tas	H. B. Bennett[6, 7]	J. O. Robson[8]

[5] The term "area" was adopted rather than the more obvious "State", to prevent possible confusion in the public mind as to whether the boards were State or Commonwealth agencies.

[6] Sir Philip Goldfinch, KBE. General Manager, Colonial Sugar Refining Co, 1928-43; Chairman NSW Board of Area Management 1940-43. B. Gosport, Hampshire, Eng, 13 Apr 1884. Died 7 Apr 1943.

[7] J. W. J. Byrne, MBE. Senior Investigation Officer, Taxation Dept, to 1940; Secretary and Accountant, NSW Board of Area Management, 1940-43, Chief Executive Officer 1943-45. B. Forbes, NSW, 18 Feb 1899.

[8] A. A. Tregear, BCom. Clerk Assistant, House of Representatives, Canberra, to 1940; Secretary, Vic Board of Area Management, 1940-41; Clerk of House since 1955. B. Port Melbourne, Vic, 15 May 1896.

[9] Col D. E. Evans, DSO, VD. (Served 1st AIF.) Chairman, Director, Evans Deakin and Co Ltd; Chairman, Qld Board of Area Management, 1940-41. B. Geelong, Vic, 8 May 1885. Died 1 Dec 1951.

[1] D. Sutherland. Former Deputy Commissioner for National Insurance, Qld, and Senior Inspector Auditor-General's staff; Secretary, Qld Board of Area Management, 1940-44. Of Brisbane; b. Edinburgh, Scotland, 14 Aug 1882.

[2] Hon Sir Frank Perry, MBE. Chairman and President Metal Industries Association of SA 1940-48; Chairman SA Board of Area Management 1940-45. B. Gawler, SA, 4 Feb 1887.

[3] S. Lillywhite, MBE. Accountant, PMG's Dept, SA, 1931-40; Secretary, SA Board of Area Management, 1940-45; State Controller, Dept of Munitions, 1945-48. Of Adelaide; b. Magill, SA, 1 Nov 1882.

[4] R. O. Law. Chairman WA Board of Area Management 1940-45; General Manager Metropolitan Brick Co Ltd, Perth, 1940-47. B. Ballarat, Vic, 20 Sep 1867. Died 22 Sep 1947.

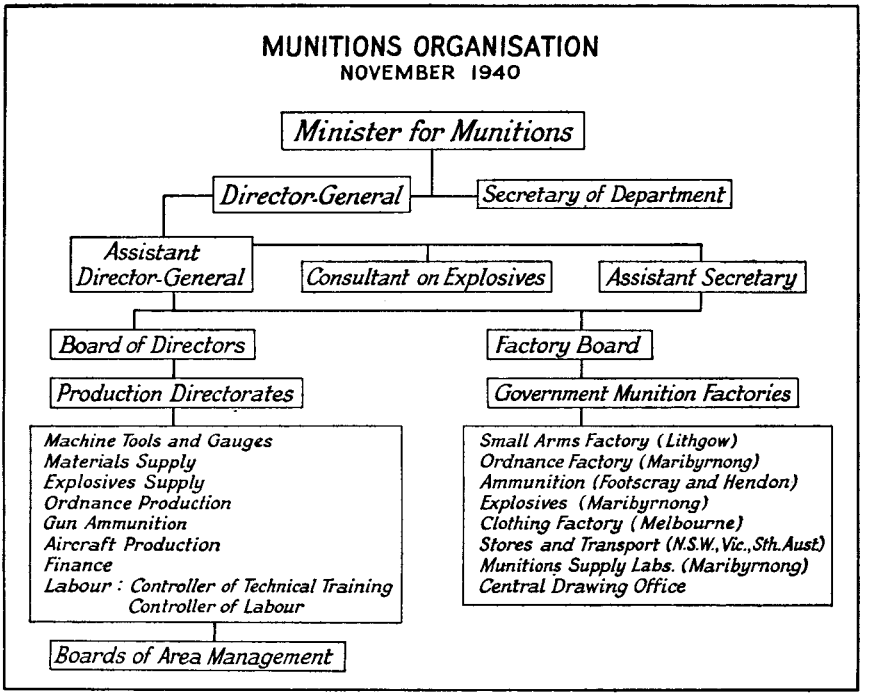
[5] A. A. C. Ramm, MBE. Sub-accountant, PMG's Dept, Perth, to 1940; Secretary, WA Board of Area Management, 1940-45. B. Toowoomba, Qld, 23 Mar 1894.

[6] Col H. B. Bennett, ISO, MBE, ED. (Served 1st AIF.) General Manager, Tasmanian Govt Railways, 1939-44; Director of Industrial Developt, Tas, 1944-53; Chairman, Tas Board of Area Management, 1940-45. B. Mt Egerton, Vic, 24 May 1889.

[7] Mr David Meredith, Manager of the Electrolytic Zinc Co of Aust Ltd, was appointed chairman at the outset but he retired after a month or so in favour of Col Bennett.

[8] J. O. Robson. Federal Dep Commissioner of Taxation, Tas, 1938-48. B. Collingwood, Vic, 15 Jan 1883.

It was not easy to define where the functions of the directorates ended and those of the boards began. Put briefly, the directorates were responsible for planning and production and the boards for managing the projects within their respective areas. This left the directors free to turn their attention to the new developments that constantly presented themselves. It also left them free to coordinate the management functions of the Boards of Area Management when a particular project was the concern of more than one State. For example, the Director of Ordnance Production had to see that 25-pounder components made in South Australia reached the assembly line in Victoria at the appropriate time; the Director of Machine Tools had to see that machine tools made in Victoria were delivered to New South Wales or wherever they were wanted. Likewise, it was a directorate's function to pool information and to see that new techniques developed in one State were quickly transmitted to the other States. By the nature of things Boards of Area Management looked at matters from the State point of view, whereas the directors were obliged to take the national viewpoint. It was the business of the boards to see that every possible productive agency in their respective States was being used and effectively coordinated with others to fulfil the program of munitions production allotted to them. The boards administered armament



annexes. They used large industrial organisations not only as manufacturers but also as centres for farming out components to small-scale manufacturers—that is, as coordinating contractors. The over-all planning

was done by the central body working directly under Lewis so that the interests of the country as a whole could be approached dispassionately and with regard to a full and effective coordination of all available resources.

In administering the government factories Lewis was assisted by the Factory Board. He was completely satisfied with the organisation which existed to run these factories and saw no reason for placing any of them under the administration of the directorates. The dual nature of the Department of Munitions may be seen from the accompanying chart; it has been simplified by omitting some of the purely administrative details.

This, then, was the structure of the largest manufacturing and producing organisation ever established in Australia, which together with the appointment for its direction and control of a group of outstanding industrialists and public servants, was completed well within six days.

At the inaugural meeting of the Department of Munitions held on 25th June 1940, Lewis said that according to preliminary advices of Service requirements the probable demands would be:[9]

252	anti-aircraft guns
840	field guns
722	anti-tank guns
121	light anti-aircraft guns
1,746	trench mortars
6,410	Bren guns
2,034	Vickers guns
50,000	rifles
6,000,000	rounds gun ammunition
1,500,000	mortar bombs
1,000,000	grenades
575,000,000	rounds of small-arms ammunition
47,000	aircraft bombs.

For their manufacture the principal materials needed would be:

10,000	tons cordite
9,000	tons TNT
585	tons carbamite
12,500	tons nitrate of soda
15,000	tons commercial and alloy steels
168,000	tons shell steel
37,000	tons copper
600	tons nickel
12,000	tons zinc.

This first order, composed almost entirely of munitions for the army and handed to Mr Lewis by the Chief of the General Staff, Sir Brudenell White,[10] on 12th June 1940, was estimated to require the construction of

[9] The principal items of munitions to be manufactured were grouped thus: 8 types of guns and mortars; 4 types of rifles and machine-guns; 8 types of cartridge cases; 11 types of fuses, gaines and primers; 8 types of shells; 2 types of shell forging; 3 types of bombs and grenades; 4 types of small arms ammunition; the varieties of explosive needed for the foregoing; factories for filling the explosives and assembling the ammunition; and machine tools needed for making additional machine tools, and the tools and gauges.

[10] Gen Sir Brudenell White, KCB, KCMG, KCVO, DSO. BGGS Aust Corps 1915-18; CGS AMF 1920-23, 1940; Chairman, C'wealth Public Service Board, 1923-28. Of Melbourne; b. St Arnaud, Vic, 23 Sep 1876. Killed in aircraft accident 13 Aug 1940.

factories that would cost approximately £14,000,000. Within little more than a month (on 15th July) the War Cabinet had approved of

Army requirements amounting to	£94,343,000
Air Force requirements (excluding aircraft) amounting to	3,750,000
Navy requirements amounting to	289,000

The smallness of the navy order was due to the fact that the navy, being ready for war at all times, did not, like the other two Services, have to start almost from zero. It always insisted on having in store its full complement of munitions, a situation which the army viewed with some envy. Much larger sums were spent on naval requirements later on. The above orders, it should be noted, were only the first of the demands made upon the Department of Munitions; they were followed by many more from all three Services, especially during the next twelve months, but it was a substantial first instalment, running as it did into nearly £100,000,000. The program to be covered by this expenditure was wide enough in scope to provide a sound foundation for the manufacturing capacity from which all later demands could be developed. The Chief of the General Staff had stated that the war was expected to last for a long time, and in view of this every effort was made to see that the rapid expansion then taking place would be adequate to cater for the ultimate requirements of the war. In a speech at a press lunch on 2nd July Lewis said:

> The foundations of munitions production in Australia were well laid—for the needs of the time. Today the needs are infinitely greater. We require a vastly expanded system. In comparison with what was done in other Dominions, our pre-war system was good. We need not deceive ourselves that in past years a majority of the public would have appreciated a very heavy expenditure on munitions.

Now at last money was available to do all that was needed. At one of his meetings with the directors Lewis remarked: "In the past we have had almost unlimited time but little money; now we have almost unlimited money but little time." All that was now needed was the will of the community to produce its utmost effort: manufacturers with their organisations and machinery, employees with their skill and enthusiasm.

The Director-General was also furnished by the Defence Committee, acting upon the advice of the three Chiefs of Staff, with a list comprising aircraft, merchant vessels, and railway rolling stock in which the order of urgency of supply was indicated. The question of priorities was always a complicated one. The Department of Munitions had no responsibility for deciding the order in which different items were to be made; that was a matter for the three Services to decide among themselves on the basis of strategic considerations. Each Service set out the items it wanted in order of priority. These lists were submitted to the Defence Committee. The Chiefs of Staff, after some argument, would accept or modify each other's claims, assign a priority rating to each item, and combine them into one list.

Once the Chiefs of Staff had thus set out their requirements, the Department of Munitions had then to decide upon priorities of manpower, materials and equipment among the different manufacturers. Though the complexity of the munitions program made it particularly difficult to allot

priorities for materials, this was generally achieved without detriment to the progress of manufacturing. When conflict arose in respect of priorities between the Services or other government departments, the matter was referred to the War Cabinet.

After the Department of Munitions had been split off from the Department of Supply and Development,[1] the latter was left with the responsibility for supply, "other than munitions, e.g. clothing and other personal equipment for the services, foodstuffs and stores of all kinds". While carrying on its earlier function of surveying Australian industrial capacity and essential supplies necessary for the security of the Commonwealth, the department undertook to control the production of minerals and metals other than those needed for munitions, and to promote the manufacture of indigenous liquid fuels (including shale oil, power alcohol and benzol), and the use of other substitutes for imported liquid fuels (particularly producer gas).[2]

No great extension of manufacture of munitions such as that undertaken in June 1940 was possible until commercial industry had been properly instructed on the technical requirements of manufacturing equipment for the Services, especially the need to conform strictly with drawings and specifications, often to very fine tolerances.

The only organisations with the technical staffs capable of explaining these requirements to the manufacturers were the government munitions factories, which under Leighton's scheme had been planned partly as technical schools for just this purpose, and the Inspection Branches of the Services. As was to be expected, the Munitions Supply Laboratories and the government factories advised commercial industry in such matters as methods of manufacture, provision of tools and gauges, and the testing of raw materials. In the early stages of the war especially, the Inspection Branch of the Army[3] under Colonel Gipps and the smaller Naval Ordnance Inspection Service under Commander Nurse[5] also gave much help.

Although industry was acquainted with the principles of mass production and some branches had had experience in the manufacture of components to precise measurements, most of them had to learn that the tolerances and tests necessary for war materials were much more exacting than they had been accustomed to. It fell to the inspection services to teach industry something of the standards required.[6] This they did with

[1] When in Oct 1942 this department was assigned the responsibility for shipping, its name was changed to Dept of Supply and Shipping.

[2] It also assumed other functions, but these are not relevant to the main theme of this volume.

[3] Army Inspection also acted for the air force in many matters. The Directorate of Aircraft Production maintained a separate Inspection Branch specifically for aircraft manufacture.

[5] Engr Capt E. S. Nurse, RAN. (HMS *Glorious* 1917-18.) Chief Inspector of Naval Ordnance; Chief Naval Representative, Dept of Supply, since 1955. Of Toorak, Vic; b. 22 Nov 1899.

[6] Brig J. K. Coffey recalled the story of a carpenter and a fitter who were talking one day in a large private factory. The carpenter was complaining that these Army Inspection people were most unreasonable: they were expecting him to work to 1/16 inch. The fitter replied, "Oh, you're lucky—they want me to work to thous." "What's a thou?" asked the carpenter, "how many of them to an inch?" "Oh, I don't know—millions of the bastards I expect." The plain fact was, said Coffey, that very few factory engineers and tradesmen could read a properly toleranced drawing, and they had to be taught to do so before production could begin.

remarkable efficiency when it is considered that they were compelled to dilute their own small staffs with untrained men and train them and many small factory staffs at the same time. Not until well into 1941 was the bulk of this work taken over by the production directorates.

Instruction, however, was a minor role of the inspection services; their primary function was to guarantee the high quality and performance of munitions. Though they came under fire at times for being too critical and exacting, no one intimate with the details of wartime production would deny that they did an excellent job. In an official tribute paid to Gipps towards the end of the war it was said that in no instance did his organisation fail to meet every need, despite the immense quantities of munitions handled, many of new types and designs and manufactured by new techniques.[7] Hundreds of millions of pounds' worth of equipment passed through his hands; his certificate of quality was accepted not only by the Australian Services but by those of the other Allied countries as well. It was with good reason the United States Army, on arrival in Australia, asked that Gipps should be made responsible for acceptance tests for munitions made locally to their order.

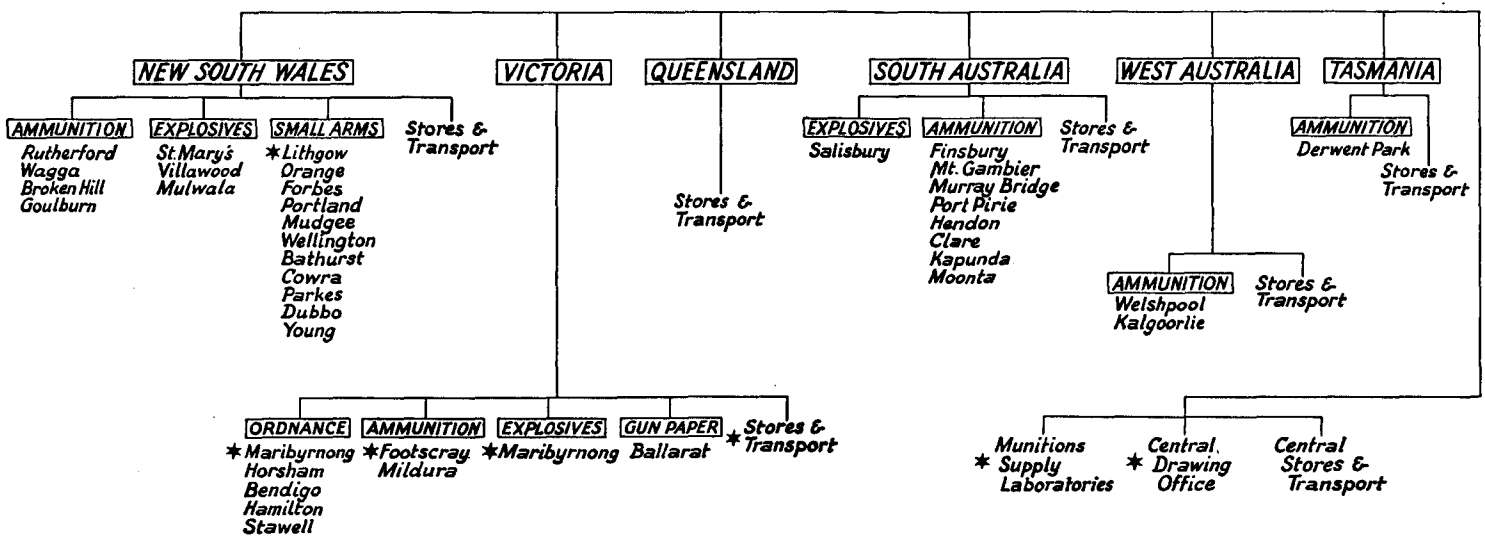
The Department of Munitions could not always proceed directly to the manufacture of all the vast quantities of munitions that had been ordered. Often it had first to build factories to manufacture the materials and machines that would be required, and then the factories where the actual munitions were to be made. Lewis attacked the problem of expanding munitions production by concentrating on two main fronts: firstly by the construction of additional government factories, and secondly by increasing the number of annexes. By the middle of 1943, at the floodtide of the munitions drive, the number of government factories had risen from 4 (early in 1940) to 39, of which 17 were devoted to making ammunition, 6 to explosives and filling, 5 to ordnance and shell, 11 to small arms and machine guns. In the same period the number of annexes was increased from the original 24 to 213.

The ruthless appropriation of materials and labour involved in all this new construction and direct war production threatened the stability of the "non-military sector" of the country's economy, and with it the "home front". Some industries, especially those concerned with the supply of such raw materials as steel, expanded under the stimulus of war; some —the primary industries, for example—suffered heavy losses of manpower; while others again—unessential or luxury industries—found they had no place in total war. In order to lessen the impact of this disruption of industry on the community the Menzies Government set up a Department of War Organisation of Industry in June 1941, but owing to the instability of the political situation which marked the "distant war" period

[7] Munitions Dept Newsletter of 25 May 1945.

MUNITIONS ESTABLISHMENTS

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* *Factories operating before 1939*

it was not fully drafted until some months later when a Labour Government under Mr Curtin[8] had taken office.[9]

The entry of Japan into the war did much to hasten "a systematic attempt to reorganise the non-military sector of the community". A few days after this event, spontaneous offers of help came from the Associated Chambers of Manufactures, the Associated Chambers of Commerce, the Central Council of Employers, and the Council of Fire and Accident Underwriters. In a joint letter to the Prime Minister on 18th December they said: "It is fully recognised that the whole future of Australia is at stake and that industry and commerce, in common with all other interests, must be subordinated to the imperative necessity of national defence."

Through the new Department for War Organisation of Industry the Government set out to achieve, *inter alia,* the following objectives:

1. To devote an increased proportion of labour and plant to war production in all industries which could contribute to the war program.
2. To release labour, materials and equipment from non-essential production by:
   (*a*) reducing the production of non-essential services and commodities;
   (*b*) eliminating unnecessary varieties and packaging wherever these retained labour and materials that could be used for war purposes;
   (*c*) rationalising distribution wherever this promised economy in manpower and other resources.

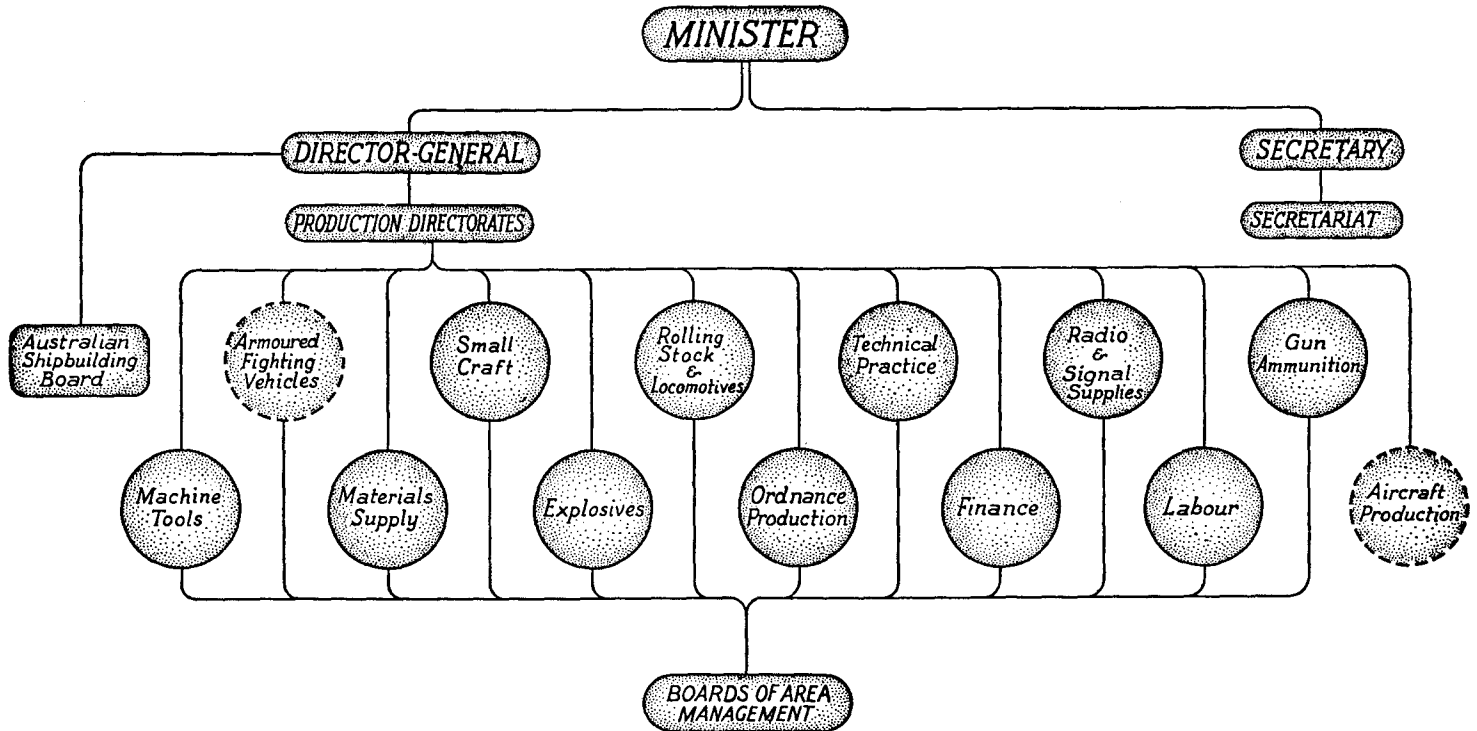
Much of this rationalisation of industry represented a pushing to the limit of the principles advocated by the Standards Association of Australia. Thus in the elimination of unnecessary diversification of types of manufacture the major tobacco companies reduced the number of packs of tobacco and cigarettes from 763 before the war to 17 by 1943. The number of varieties of domestic glassware was reduced from 800 to 85; dry batteries from 478 to 71, and gardening tools from 215 to 55. Economies were effected by simplifying the design of clothing.[10] The cuffless trousers and buttonless sleeves of the "Victory suit", the tail-less shirt and the unlined hats with their unwelted brims may not have been great sartorial successes but they were at least symbols of rationalisation. The zoning of deliveries and services, reduction of transport of unessential goods, control of building, advertising and unessential industries, as well as the control of new industries, were all manifestations of the rationalisation of industry. For a full assessment of their influence on war production, Professor Butlin's volume in this series may be consulted.

While the basic plan for the utilisation of commercial industry remained unchanged throughout the war, there were considerable changes in the Department of Munitions itself, including an expansion in the number of directorates. When the Cabinet was reorganised in June 1941, a portfolio was created for Aircraft Production and the Aircraft Directorate was

[8] Rt Hon J. Curtin. MHR 1928-31, 1934-45; Prime Minister and Minister for Defence 1941-45. Of Cottesloe, WA; b. Creswick, Vic, 8 Jan 1885. Died 5 Jul 1945.
[9] Hon E. S. Spooner, first Minister for War Organisation of Industry, was succeeded in Oct 1941 by Hon J. J. Dedman.
[10] E. R. Walker, *The Australian Economy in War and Reconstruction* (1947).

MUNITIONS ORGANISATION

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detached from Munitions to become a separate department. It was a remarkable tribute to Lewis that the Labour Government which took office soon after the establishment of the Department of Aircraft Production promptly appointed him Director-General of Aircraft Production in addition to his existing appointment as Director-General of Munitions.

As the war progressed the scope of the Department of Munitions was increased in some directions and decreased in others. Difficulties in the early attempts to make tanks brought into existence a separate Directorate of Armoured Fighting Vehicles. Similarly the unprecedented demand for radar and telecommunication equipment prompted the formation of a Directorate of Radio and Signal Supplies. The activities of several sections of the department became so extensive and complex that it was occasionally forced to consider questions outside its province. Lewis was averse to the Munitions Department's dealing with matters beyond its charter. He did, however, consider that labour supply, welfare and technical training came within its ambit and it therefore came as a surprise to him when, in October 1940, these activities were made the subject of a special ministry, the Department of Labour and National Service, which was placed under Mr Holt,[1] previously Assistant Minister for Munitions. Later, when the Commonwealth Departments of Transport and Health were formed, the corresponding activities of the Department of Munitions were transferred to the new departments. However Lewis, with the help of Jensen (who was now Secretary of the Department of Munitions) managed to evolve satisfactory working arrangements with these new departments.

The entry of Japan into the war and the threat of invasion which hung over Australia in the months that followed, gave the greatest stimulus of all to the production of munitions. Much anxiety was felt lest Australia be cut off altogether from oversea supplies of any kind. Government factories, especially those for making explosives and ammunition, began to arise wherever there were sources of labour: in the suburbs of the great cities and in the quiet countryside. Establishments in the rural areas became especially numerous, many of them representing a second line of defence in the event of the big cities being bombed out. The trend which had been developing during 1941 for export of munitions abroad, particularly to India, the United Kingdom and the Netherlands East Indies, practically disappeared; but with the arrival of American forces many new supply problems were created. In 1942 the great industrial effort underlying the munitions program was moving towards its climax. The whole of commercial industry, except that needed to provide the minimum of civilian needs, was pressed into service. The munitions undertaking became so complex that to give a chronological account would make it almost impossible to follow the development of any particular project. From now on, therefore, the major projects will be followed separately. Even so it will not be possible to do more than touch on a few of the more important achievements.

[1] Rt Hon H. E. Holt. MHR since 1935; Minister for Labour and National Service 1940-41 and since 1949; Minister for Immigration 1949-56. B. Sydney, 5 Aug 1908.

APPENDIX

List of Establishments housing Government Annexes

NEW SOUTH WALES

Establishment	*Project*
Stewarts and Lloyds (Aust) Pty Ltd Newcastle	25-pdr shell forgings 5.5-in shell machining
NSW Railway Workshops, Eveleigh	Shell
NSW Railways, Chullora	Originally tank assembly, later auxiliary marine craft
NSW Govt Railway Workshops, Eveleigh	Radar equipment
Colonial Sugar Refining Co, Pyrmont	Activated carbon Shell Glycerine
R. B. Davies Pty Ltd, Marrickville	Grenades 36 Grenades 68
Duly and Hansford Pty Ltd, Marrickville	Fuses, Gaines
Electricity Meter Manufacturing Co Pty Ltd, Waterloo	Fuses 20-mm Oerlikon shell
Electricity Meter Manufacturing Co Pty Ltd (Westinghouse Rosebery Works), Waterloo	Primers
Amalgamated Wireless (A/sia) Ltd, Ashfield	Fuses 20-mm Oerlikon shell
Commonwealth Steel Co Ltd, Waratah	Shell and 4.2-in mortar bombs Gun forgings
Gilbert and Barker Pty Ltd, Alexandria	Fuse, contact mine, A.T. Fuse 231
E.R.L. Products Pty Ltd, Glebe	Aircraft bomb pistols Primers
Plumbs (Aust) Pty Ltd, Alexandria	Shell
Westinghouse Brake (Aust) Pty Ltd, Concord	Depth charge pistols and primers
Broken Hill Pty Company Ltd, Newcastle	Shot Shell Magnesium powder 80-ft Steel lighters
Timbrol Ltd, Rhodes	Aniline, Monoethylaniline, Diethylaniline, etc.
General Motors-Holden's Ltd, Pagewood	25-pdr Gun howitzers
Bradford Kendall Ltd, Alexandria	Aircraft bombs assembly Tank castings; general engineering Heat Treatment capacity

NEW SOUTH WALES—*continued*

Establishment	*Project*
S. T. Leigh Pty Ltd, Kensington	Fuses
Slazengers Pty Ltd, Alexandria	Rifle and Bren-gun components and boxes Filter pads for anti-gas respirators
Slazengers Pty Ltd, Putney	Auxiliary marine craft Timber creosoting
Slazengers Construction Co Pty Ltd, Newcastle	Auxiliary marine craft
Rylands Bros (Aust) Pty Ltd, Newcastle	2-pdr links and Bren-gun magazines
Lever Bros Pty Ltd, Balmain	Glycerine
Industrial Steels Ltd, Lidcombe	Tank castings and track links Bomb castings, machining and assembly
Hadfields Steelworks Ltd, Alexandria	Tank and carrier castings; general engineering
Quality Castings Pty Ltd, Waterloo	Silicon iron castings
Coote and Jorgensen Ltd, Alexandria	Tank gears and parts; components for marine craft
Sonnerdale Pty Ltd, Petersham	Gear boxes for tanks; marine engine gear boxes General capacity for production of gears
Acetone Pty Ltd, Lane Cove	Acetone
Australian Window Glass Pty Ltd, Alexandria	Optical glass
Howard Auto Cultivators, Northmead	Owen gun parts Pistols
Airzone (1931) Ltd, Camperdown	Grenades assembly
Australian Consolidated Industries Ltd, Waterloo	Mortar bomb castings
Commercial Steels and Forge Co (Aust) Pty Ltd, Lidcombe	Stores accommodation
Cooper Engineering Co Pty Ltd, Mascot	Tracer and Igniter No. 12, fuses Jigs, tools and gauges
Automatic Totalisators Ltd, Sydney	Jigs, tools and gauges
Goulburn Gas and Coke Co Ltd	Contribution towards gas mains
Sulphide Corporation Ltd, Newcastle	Nickel matte roasting
Australian Aluminium Co Pty Ltd, Granville	Aluminium scrap remelting
Davies Shephard (Sydney) Pty Ltd, Mascot	Torpedo components

NEW SOUTH WALES—*continued*

Establishment	*Project*
Sydney Williams and Co Pty Ltd, Dulwich Hill	Tools and gauges
Fletcher Springs Pty Ltd, Redfern	Small wire springs
G. E. Crane and Sons Pty Ltd, Sydney	Duralumin, alclad and aluminium sheet
Australian General Electric Ltd, Auburn	5-KVA alternators
A. W. Fairfax Pty Ltd, Fivedock	Mortar bombs, machining
Wunderlich Ltd, Rosehill	Mortar bombs, machining
Westinghouse Rosebery Pty Ltd, Waterloo	5-KVA generating sets
Imperial Chemical Industries of Aust and NZ Ltd, Botany	Chlorine, perchlorethylene, hexachlorethane
Australian Gaslight Co, Mortlake	Plant for disposal of fatty acids from Lever Bros' glycerine plant Toluol from coal gas
Silovac Electrical Products Pty Ltd, Camperdown	Tools and gauges
Clyde Engineering Co Ltd, Granville	Buildings and equipment
Ferrier and Dickinson Ltd, Marrickville	Auxiliary marine craft outfitting depot
Hastings Deering Service Ltd, Sydney	.38 pistols
Chubb's Australian Co Ltd, Sydney	Recuperator blocks
A. Goninan & Co Ltd, Newcastle	Refrigeration barges
Tulloch's Pty Ltd, Rhodes	Auxiliary marine craft
British Optical Co Pty Ltd, Darlinghurst	Optical munitions
NSW Railways, Cardiff	Tools, jigs and gauges
VICTORIA	
Chas Ruwolt Pty Ltd, Richmond	Mortar bombs Gun production, etc A.P. Shot Mortar bombs and A.P. Shot Steel barges
Chas Ruwolt Pty Ltd, Holmesglen	Armour plate castings
Victorian Railways, Newport	Shell
Victorian Railways, Melbourne	Electrical instruments
Australian Glass Manufacturers Co Pty Ltd, Spotswood	Shell machining 3.7-in Shell machining 4.5-in smoke Shell forging Fuses Diecasting Toolsetters' training school

VICTORIA—*continued*

Establishment	*Project*
H. V. McKay, Massey Harris Pty Ltd, Sunshine	Shell A.P. shot
McKenzie and Holland Pty Ltd, Newport	Fuses Aircraft practice bombs
Johns and Waygood Ltd, South Melbourne	Mortar bombs
Ford Manufacturing Co of Aust Pty Ltd, Geelong	Mines Auxiliary marine craft, with facilities for assembling and launching
No. 5 Explosives Factory, Albion (under management of ICIANZ)	TNT, Cordite 1, Carbamite, Ballistite, etc. Charcoal and Gunpowder Experimental Station.
Imperial Chemical Industries of Aust and N.Z. Ltd, Deer Park	Gunpowder Signal cartridges, Tracer shot cartridges Percussion Caps Methanol Primer caps for grenades Trench mortar cartridges A.S. Chlorosene Chlorosene packing unit Solid sodium chlorate Pure potassium and barium chlorates Sodium perchlorate
H. E. Brehaut Pty Ltd, Mont Albert	Tail units for aircraft bombs, mortar bombs
Thompsons Engineering and Pipe Co Ltd, Castlemaine	Forging, machining and testing for guns, etc. Non-ferrous forgings
John McIlwraith and Co Pty Ltd, Richmond	Fuses tracer and igniter No. 12
Sutton Tool and Gauge Manufacturing Co Pty Ltd, Northcote	Tools and gauges
Purvis Glover Engineering Pty Ltd, Footscray	Fuses Primers
W. G. Goetz and Sons Ltd, Spotswood	Fuses
J. W. Handley Pty Ltd, Abbotsford and Brunswick	Optical munitions
Dominion Can Co Pty Ltd, Melbourne	Fuses
Melbourne Iron and Steel Pty Ltd, Brooklyn	Casting of bomb ingots for Ordnance Factory Preparation and rolling of steel for A.P. shot
Australian Paper Manufacturers Ltd, Maryvale Maryvale and Melbourne	Paper wood cellulose Alpha cellulose board

VICTORIA—*continued*

Establishment	*Project*
British United Shoe Machinery Co of Aust Pty Ltd, Fitzroy	Heat treatment, anti-tank gun components Recuperators for anti-tank guns
Metropolitan Gas Co, Fitzroy	Machine-gun carriers
Ruskin Motor Bodies Ltd, West Melbourne	Assembly of aircraft bombs
Marfleet and Weight Pty Ltd, Abbotsford	Heavy machine tools
Albright and Wilson (Aust) Pty Ltd, Yarraville	Phosphorus grenades Amorphous phosphorus Calcium phosphide
Olympic Tyre and Rubber Co. Ltd, Footscray	Field telephone cable
F. L. Cook and Williams Pty Ltd, Abbotsford	Grenades
Jeffree Bros, Bendigo	Aluminium powder—flake and blown
Stanger and Co Pty Ltd, West Preston	Tools and gauges
Commonwealth Fertilisers and Chemicals Ltd, Yarraville	Pyrites roasting plant in connection with production of sulphuric acid and oleum
H. A. Chivers, Melbourne	Torpedo components
Myttons Ltd, South Melbourne	Primers
Metropolitan Gas Co, West Melbourne	Ammonia liquor
Ammonia Co of Aust Ltd, Spotswood	Ammonia liquor
Aluminium Fabrication Factory, Wangaratta (under management of Aust Aluminium Co Pty Ltd)	Aluminium fabrication
Waldown Pty Ltd, Collingwood	Electric drills and grinders
W. Watson and Sons Ltd, Tunstall	Pyrometers
Steel Co of Aust Pty Ltd, Coburg	Tank-track links
University of Melbourne	Valve manufacture investigation
Specialised Engineering Products Co, East Brighton	Torpedo components
Crusader Plate Co Pty Ltd, Abbotsford	Mortar bombs, smoke
J. Botterill and Fraser, South Melbourne	Auxiliary marine craft
QUEENSLAND	
Toowoomba Foundry Pty Ltd, Toowoomba	Primers
Metal Products Pty Ltd, Albion	Shell igniters, gaines
Ford Motor Co of Aust Pty Ltd, Eagle Farm	Water transport barges
Queensland Railways, Ipswich	Tools, jigs and gauges

SOUTH AUSTRALIA

Establishment	*Project*
South Australian Railways, Islington	Shell machining Shell forging
Pope Products Ltd, Beverley	Gaines, Aircraft practice bombs
General Motors-Holden's Ltd, Woodville	Aircraft bombs
Woodville and Beverley	Gun production Polsten gun
Woodville and Birkenhead	Torpedo components
Woodville	Ammunition boxes 40-mm shell
Broken Hill Pty Co Ltd, Whyalla	Shell Forgings
Kelvinator (Aust) Pty Ltd, Keswick	Primers
Perry Engineering Co, Mile End	Shell forgings and machining Forgings
Richards Industries Ltd, Keswick	Cartridge containers, etc
B. S. Williams, trading as Wheatley and Williams, Bowden	Non-ferrous castings
David Shearer Ltd, Mannum	Track links for machine-gun carriers
Southcott Ltd, Adelaide	Heat treatment of tools and gauges
Horwood Bagshaw Ltd, Mile End	Anti-tank guns
Wiles Chromium and Electroplating Co Ltd, Mile End	Wiles mobile cookers
British Tube Mills (Aust) Pty Ltd, Kilburn	Oil and fuel bottles for torpedoes Cold-drawn steel tubes
Stewarts and Lloyds (S.A.) Pty Ltd, Kilburn	Hot-rolled tubes for hollows
I.C.I.A.N.Z. Ltd, Osborne	Calcium chloride
S. Aust. Railways, Islington	Tools, jigs and gauges

WESTERN AUSTRALIA

W.A. Railways, Midland Junction	Shell forging and machining
Geo Hill and Co, Perth	Primers
Boltons Ltd, Perth	Mortar bombs, machining
Hadfields (W.A.) Ltd, Perth	Mortar bombs, castings
F. Tough, Perth	Optical munitions
West Australian Government: Midland Junction Railway Workshops and State Engineering Works, North Fremantle	Development of steel casting capacity
W.A. Railways, Midland Junction	Tools, jigs and gauges

TASMANIA

Establishment	*Project*
Tasmanian Railways, Launceston	Shell, Mortar bombs
Henry Jones and Co Pty Ltd, Hobart	Primers
Associated Pulp and Paper Mills Ltd, Burnie	Chlorine
E. N. Waterworth Annexe, University Grounds, Hobart	Prisms and optical munitions
Electrolytic Zinc of Aust Ltd, Risdon	Zinc alloy
Tasmanian Railways, Launceston	Tools, jigs and gauges

OPTICAL MUNITIONS

The Optical Munitions Project was distributed among the following organisations, in order of importance:

University of Melbourne
Commonwealth Solar Observatory
E. N. Waterworth Annexe, Hobart
University of Sydney
Australian Optical Co Ltd, Sydney and Melbourne
National Standards Laboratory
University of Western Australia
University of Adelaide
Council for Scientific and Industrial Research
Sydney Technical College
Melbourne Technical College
British Optical Co Pty Ltd, Sydney

CHAPTER 3

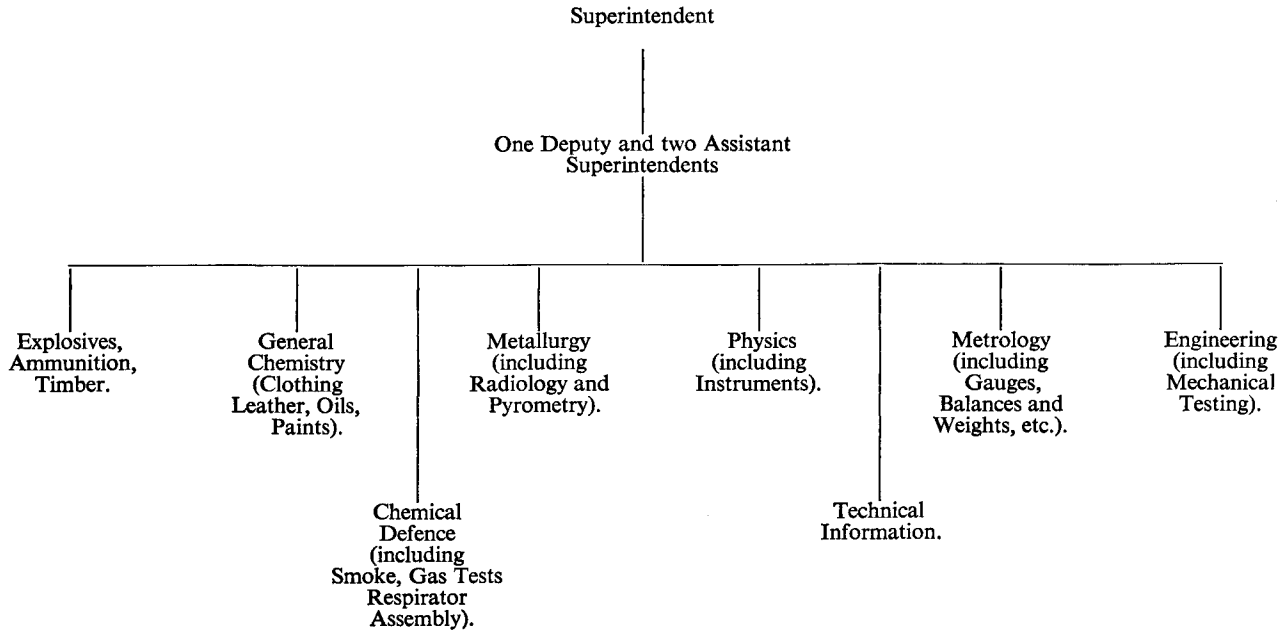
THE MOBILISATION OF SCIENCE

FULL mobilisation of the scientific resources of the Commonwealth lagged behind that of industry. Certainly nothing occurred in science to parallel the changes in industry during the period immediately after June 1940. The need to mobilise science was more apparent to scientists than it was to administrators, who for the most part lacked a scientific background. Furthermore, it was not so easy to achieve. At the outbreak of war the Commonwealth's scientific resources were considerable. The two strongest organisations, the Council for Scientific and Industrial Research and the Munitions Supply Laboratories, whose activities are indicated in the accompanying charts, possessed between them staffs of which about 1,000 could be classified as scientists. It is difficult to make any precise estimate of the total number of scientists then at the disposal of the Commonwealth, partly because no thorough survey had been made of scientific manpower, partly because of the difficulty of defining the category. A contemporary estimate placed the number between 3,000 and 4,000.[1] Those not within the two principal organisations were distributed among the State government scientific services in agriculture, mining, engineering and health, and the six Australian universities. The last group included a large proportion of the most active scientific research workers.

There was no question that from the beginning of the war the resources of the Munitions Supply Laboratories were fully engaged on war work. Similarly the policy of the Executive of the C.S.I.R. was that its divisions should suspend activities on most of their long-range research programs and concentrate on work of immediate bearing on the war effort. It was among scientists outside these organisations that a feeling of frustration developed in the early years of the war because their services were not being fully used for the defence of the country. Recognition of the need for a more thorough coordination of scientific resources came from the scientists themselves. Editorials in scientific journals such as the *Australian Journal of Science* made it clear that they were concerned at the overlapping and oversight arising from the lack of organisation of scientific effort. Instances of two or more laboratories working on the same problem but unaware of each other's efforts were not uncommon. University scientists were working on problems in the belief that they were making a useful contribution to the war effort when in fact the same problem had already been solved in some government laboratory. It was not for want of effort on the part of the Australian National Research Council, which then comprised about 200 of Australia's leading scientists, that this state of affairs was allowed to persist during the early years of the war.

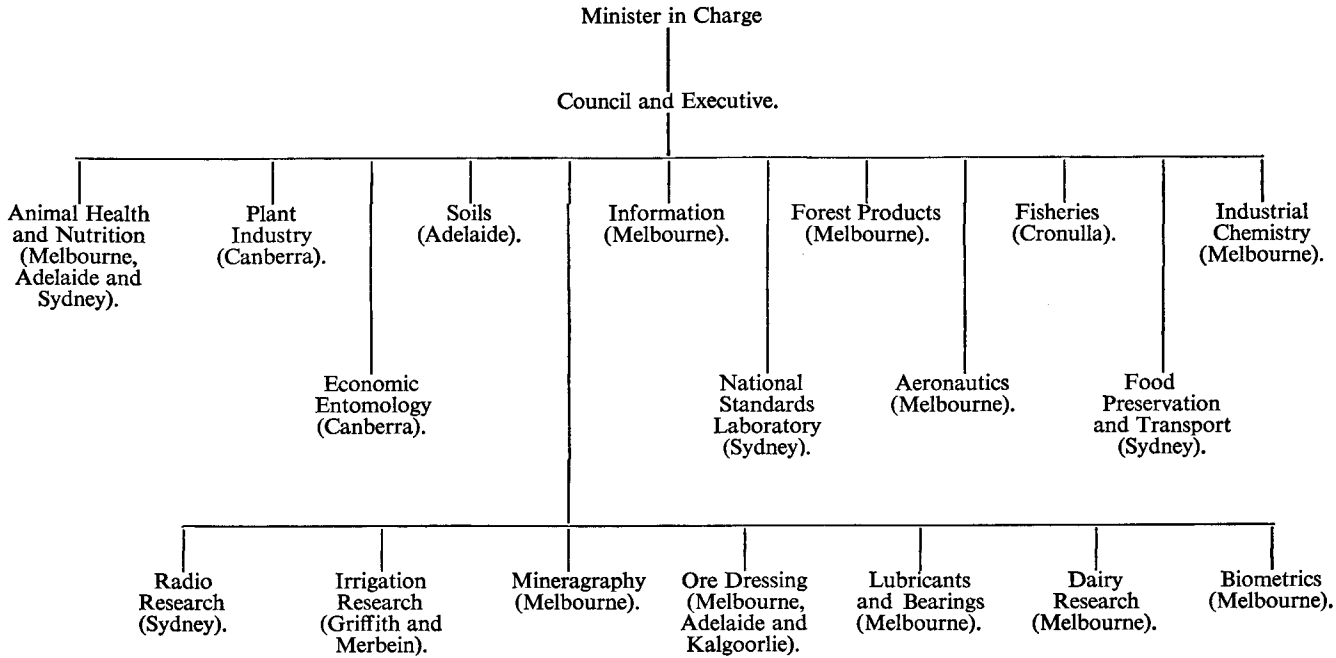
[1] This figure, taken from "Science in Vacuo", by "Observer", *Australian Quarterly*, Sep 1942, probably refers to science graduates. Not everyone would agree to call a graduate in science a scientist. Some writers prefer to restrict this term to those who are or have been engaged in scientific research.

ORGANIZATION OF MUNITIONS SUPPLY LABORATORIES (1943)



Reprinted from *Science on Service*, a Directory of Scientific Resources in Australia (1943).

ORGANIZATION OF COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH (1943)



The council, which aspired to act as

1. the collective voice of Australian scientists,
2. the adviser to Commonwealth and State Governments on scientific matters of national importance, and
3. the organiser of scientific bodies and scientific workers into an effective unit for use in national emergencies,

had placed its services at the disposal of the Commonwealth Government soon after the outbreak of war.

When asked by the Prime Minister, Mr Menzies, for advice on the best way of using the country's scientific resources, the council recommended the formation of a body similar to the British Scientific Advisory Committee. This proposal did not find favour with the C.S.I.R., and the Government, which was always inclined to listen to the advice of its own organisation in preference to that of the A.N.R.C., rejected the recommendation. The Prime Minister did, however, approve of a scheme that gave the A.N.R.C. a subsidiary role enabling one of its representatives to confer periodically with the Executive Committee of the C.S.I.R. and to attend conferences with government departments when appropriate matters were being discussed. Commenting on this and the relationship of science to the war, an editorial of the *Australian Journal of Science* stated:[2]

> The National Research Council, and for that matter most Australian scientific men, have no wish to dabble in politics. All they wish is to see scientific skill and experience intelligently harnessed by their national rulers to the national effort.

Undaunted by these setbacks, the A.N.R.C. set about using its meagre resources to amplify existing registers of scientific personnel, to survey the Commonwealth's mineral resources, and by means of a questionnaire to discover the nature and extent of laboratory facilities and the scientific research in progress in Australia.

One difficulty prevalent at this time was that of locating the technical problems holding up industry. Once the Department of Supply, or later the Department of Munitions, let a contract for the manufacture of some item of equipment it was the contractor's responsibility to overcome technical difficulties that might arise in the course of its manufacture. The department was frequently unaware of the many scientific and technical problems that were delaying production. The inspection services helped to the best of their ability, but manufacturers often required more help than they could give. In Victoria and New South Wales an attempt was made to alleviate this position by the formation of voluntary Joint Technical Committees of the Chambers of Manufactures and the universities. These committees, though hampered by lack of funds and of official recognition, dealt effectively with a host of minor scientific problems but rarely handled larger, general scientific problems.

The chief spokesman for the scientists, and the most penetrating critic of the Government's failure to set up machinery by which problems aris-

[2] Vol. 3 (1941), p. 65.

ing out of the war might be transmitted to the scientist, or by which the scientist could put his proposals and ideas before the appropriate government department, was Professor Ashby,[3] Chairman of the Australian National Research Council. Although at first in favour of setting up a scientific advisory council in Australia, Ashby later came to the view that advisory functions were not enough, that the initiative for scientific inquiry should "come from the scientist and not from the administrator". He contended that government policy for making use of the services of its experts overlooked two vitally important points: training in science was needed even to recognise a scientific problem unless it had become desperate; science was powerless to take the initiative unless it could apply foresight to anticipate problems, and it was impossible to apply foresight when scientists were kept in ignorance of the necessary facts.[4]

That any particular problem needed expert knowledge was not always evident, even to the scientist, unless it happened to be in his special field; still less likely was it to be evident to civil or military administrators. As an example of this Ashby cited the need of the armed services for entomologists to fight malaria and dengue.

> Any staff officer or administrator (he wrote) knows that these diseases are spread by mosquitoes and that these mosquitoes breed in water. He is inclined to the view, therefore, that control is a simple matter. Issue a manual of hygiene. Appoint a few hygiene sergeants. The job is as good as done. What the staff officer is likely to overlook is that there are many different kinds of mosquito, some harmless and some dangerous, and that of the dangerous mosquitoes some breed in the shade and some in the sunlight, and they call for different methods of control. He is unlikely to know that hygiene sergeants are scarcely well enough equipped to recognise species of mosquito. He is unlikely to know that the *Army Manual of Hygiene and Sanitation* (reprinted with amendments, No. 1, 1940), which is the official guide to control, is so hopelessly out of date that it is a laughing stock among biologists and is prepared in complete ignorance of Australian conditions.

Another example of failure to recognise where scientific problems might arise was to be seen in the Defence Foodstuffs Advisory Council set up early in 1942. This council was formed to deal with all aspects of food supply, yet it originally contained neither an agricultural scientist nor a nutrition expert.

Ashby returned many times to the attack on the problem of establishing a satisfactory relationship between the scientist and the Government. After considerable agitation on his part the Government agreed to the National Research Council's request for the appointment of two men with scientific and industrial experience to examine the ways and means of making more effective use of the country's scientific manpower. The Prime Minister, Mr Curtin, commissioned Professor Ashby and Dr Vernon[5] to make a report

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[3] Sir Eric Ashby, DSc. Prof of Botany, Univ of Sydney, 1938-46; Counsellor and Charge d'Affaires, Australian Legation, Moscow, 1944-45; Prof of Botany, Univ of Manchester, 1947-50; President and Vice-Chancellor, Queen's Univ, Belfast, since 1950. Of Sydney; b. London, 24 Aug 1904.

[4] "Observer" (almost certainly Prof Ashby).

[5] J. Vernon, BSc, PhD. Chief Chemist, Colonial Sugar Refining Co, 1938-51, later Senior Executive Officer. B. Tamworth, NSW, 13 Jun 1910.

on the enlistment of scientific resources in the war effort. They were authorised to inquire into and report upon:

1. the procedure adopted at present when scientific problems arise which are related to war activities and which are outside the scope of the scientific staff of the industry and the government department concerned;
2. the proportion of these problems which require some experimental investigation and the difficulties which are experienced in finding scientific men who can undertake such investigations;
3. the value to war industries and government departments of some simple and regular means of assigning such problems to appropriate scientific men, in addition to the means existing at present;
4. the extent to which scientific skill and equipment outside the government service are being used in the war effort and the means whereby fuller use might be made of the scientific resources (apart from training facilities) of universities, research institutions and technical colleges.

Ashby and Vernon took full advantage of the unique opportunity thus given them and soon substantiated the contention that science was not being used to the fullest extent possible. One of the principal reasons for this, they said, was that there were "not enough bridges between the places where problems arise and the men who can tackle them".[6] They were thus led to recommend that the Government should form a scientific liaison bureau with an initial vote of £15,000. Its director, who they suggested might be nominated by the Executive Committee of the C.S.I.R., should be directly responsible to the Minister in charge of the C.S.I.R. They discussed their proposals with the Prime Minister and Treasurer, who agreed that the bureau should be set up immediately. Despite this there were many exasperating delays (the country at this time lay under the threat of a Japanese invasion) in bringing the bureau into existence. There were protracted discussions on whether or not the bureau should be answerable to the C.S.I.R. Ashby and Vernon were emphatic that it was essential for the director of the bureau to be responsible for his own decisions and not answerable to the permanent head of a department. This was finally agreed to, and on 9th July 1942 the Prime Minister publicly announced that a Scientific Liaison Bureau would be formed.

Then followed yet another delay, this time due to the fact, pointed out by the Executive Committee of the C.S.I.R., that the way in which it was proposed to finance the bureau (through a grant paid into the Science and Industry Investigation Trust Account) contravened the Act governing the operation of this account. Under the Act the C.S.I.R., as trustee, was the only body that could make recommendations to the Minister regarding the allocation of these funds; this power could not be delegated and thus it would be impossible for the director of the bureau to be independent of the C.S.I.R. As a way out of this impasse the War Cabinet decided that the bureau should be independent of but closely associated with the Department of War Organisation of Industry. At last,

[6] E. Ashby and J. Vernon, "The Enlistment of Scientific Resources in the War Effort", report to the Prime Minister, 21 Apr 1942.

on 1st December 1942, the bureau became an accomplished fact and Ashby was invited to become its director, a post which he accepted without salary.

The functions of the bureau as decided by the War Cabinet were:

(*a*) to ensure that scientific problems which arise in the Services, government departments and war industries are promptly brought to the notice of suitable scientific men; and that, if necessary, experimental work is carried out to solve these problems;

(*b*) to become familiar with the major facilities for scientific work in government and non-government laboratories, so that problems can be directed into the most appropriate channels, and replication of effort can be minimised;

(*c*) to supply contacts between men who encounter scientific problems and men who can solve them, where these contacts are not already established by existing committees, etc;

(*d*) to arrange, where no other channels exist, for cooperative work between government and non-government scientific departments;

(*e*) to promote, wherever possible, the application of scientific work to war needs in the Services, government departments and war industries.

The director's powers were:

(i) authority to set up a staff consisting of liaison officers, and to have secretarial assistance;

(ii) authority to have officers in such cities as may be necessary;

(iii) authority to spend funds on travelling and maintenance of staff and of scientific men enlisted on war problems;

(iv) authority to draw on a trust fund to launch urgent scientific inquiries arising out of the war;

(v) authority to form a panel of non-government scientists, to establish contact with and to obtain information from government laboratories and government committees dealing with scientific problems;

(vi) authority to enlist the help of universities, technical colleges, non-government institutions and industries, and, where practicable, of government laboratories in the solution of technical problems arising out of the war;

(vii) direct access to a Cabinet Minister.

By March 1943 the bureau was fully organised in all States, with deputy directors in Sydney and Melbourne and honorary officers acting in a similar capacity in other State capitals and in Newcastle. Liaison with the army had been established through the appointment of a scientist with the rank of major who was attached to the Research Section of the Adjutant-General's Department; liaison was also established with the Departments of Supply and Shipping, Commerce and Agriculture, and the War Organisation of Industry; also with the Munitions Supply Laboratories and the Council for Scientific and Industrial Research, and all organisations—universities, technical colleges and research institutes—possessing laboratory facilities. The bureau made no attempt to set up an information service. Its liaison with the Information Section of the C.S.I.R. was therefore especially important, since the C.S.I.R. had assumed responsibility for scientific liaison between the Commonwealth and Britain and the United States.

Once the bureau was firmly established, Ashby resigned from his post as honorary director. He was succeeded by his assistant director, Mr Cummins,[7] who was appointed to full-time duty.

The bureau did not aim at becoming a channel through which all scientific information bearing on the war should pass; its aim was to add to, not to replace, the many close contacts which already existed between government departments and scientists. Nowhere were these contacts more numerous or more effective than in the fields of physics. Physicists, through their own professional organisation, had formed a most successful group known as the Optical Munitions Panel; another group, within the C.S.I.R., was doing excellent work on radar. With these the bureau had little or nothing to do.

In collaboration with the Australian Chemical Institute and the Association of Scientific Workers, the bureau published *A Directory of Scientific Resources,*[8] the first of its kind prepared in Australia. The directory gave a brief account of the main function of all the government scientific organisations; for each State it also gave a classified list of subjects and organisations most suited for giving advice or doing research on them. Most of the day-to-day scientific and technical problems encountered by the Services and wartime industries had already been solved in other parts of the world, and a good deal of the bureau's activities was designed to bring these solutions to the notice of the appropriate experts. The bureau did not undertake investigations, but when required it had power to enlist a scientific group to tackle problems.

Among such problems was the preparation for the R.A.A.F. of a booklet entitled *Friendly Fruit and Vegetables,* the object of which was to give servicemen information on jungle plants which would, in the event of necessity, enable them to live on the country. The booklet, which was prepared by Professor Herbert,[9] was given wide circulation by both the R.A.A.F. and the army. The great majority of the problems submitted to the bureau were of a chemical or metallurgical nature; next in order were biological, physical and medical problems.

A typical problem handled by the bureau was that met by the army in its attempt to use locally-produced diatomaceous earth as a filtering medium in the purification of water. This substitution had been forced on the army by the curtailment of oversea supplies on which it had hitherto depended. Considerable trouble was being experienced because the local material was so variable in quality that it could not be safely used without first being tested. What the army wanted was some simple, easily-applied, small-scale test to assess the filtering qualities of diatomaceous earth. Experts capable of answering this question were found among the soil chemists of the Waite Agricultural Research Institute in Adelaide. After

[7] J. E. Cummins, MSc. Research Officer, CSIR Information Section, 1940-45; Chief Scientific Liaison Officer, London, 1948-54, Washington since 1955. B. Perth, WA, 21 Oct 1902.

[8] *Science on Service—A Directory of Scientific Resources in Australia* (1943).

[9] Prof D. A. Herbert, DSc. Lecturer in Botany, Univ of Qld, 1924-46, Assoc Professor 1946-48, Professor since 1948. B. Diamond Creek, Vic, 17 Jun 1898.
Dr Herbert prepared the booklet in collaboration with Messrs C. T. White and R. E. P. Dwyer.

some experimental work they supplied the Army Hygiene Section with all the details it required on methods of testing.

Another problem came from the aircraft industry, in connection with welding aluminium. None of the three glasses then in use for welders' goggles prevented strain and headaches. The reason for this was that the standard glasses were designed to protect the eyes against ultraviolet light, whereas in aluminium welding protection was needed not only against ultraviolet but also against the intense visible light emitted by the fluxes (salts of lithium) used in this form of welding. The brilliance of the light was so extreme that it prevented the welder from seeing his work, and the consequent eyestrain had a serious effect on his output; in some instances there was a risk of permanent damage to the retina of the eye. As a result of tests made on its behalf by the Chemistry Department of the University of Melbourne and the National Standards Laboratory in Sydney, the bureau was able to recommend the use of a special signal green glass which was found to reduce glare satisfactorily without reducing the visibility of the weld. When it was found that the glass was not then being made in Australia and that imported stocks were almost exhausted, the problem was taken up by the National Standards Laboratory, which advised manufacturers on the type and nature of glass required. The Crown Crystal Glass Company was able to provide a satisfactory substitute.

These examples are cited to illustrate how the bureau functioned and the kinds of inquiry with which it dealt. By far the most important of its contributions to the war effort was its coordination of the scientific attack on the problem of rendering material and equipment proof against the ravages of moulds and mildews in the tropics. It had found that investigational work on the rot proofing of cotton duck for tents was being carried out in three different capital cities in Australia and by at least six organisations, all with very little knowledge of each other's work and progress. So important did the scientific work on tropic proofing become in the latter part of the war that a separate chapter will be devoted to it.

CHAPTER 4

RAW MATERIALS: STEEL[1]

AFTER the formation of the Department of Munitions in June 1940, control of the supply of raw materials—principally metals and heavy chemicals—consumed by all the industries engaged in making munitions, was in the hands of the Directorate of Materials Supply headed by Sir Colin Fraser. This directorate arranged for the rationing of these materials where necessary and for ensuring that the needs of defence were given their appropriate priority. The comparatively small number of suppliers of base metals and heavy chemicals in Australia allowed effective control of these raw materials to be imposed at the source of supply.[2] The Broken Hill Proprietary Company Ltd had a monopoly of the iron and steel industry and the "Collins House Group" dominated the production of non-ferrous metals; heavy chemical industry was almost entirely in the hands of Imperial Chemical Industries of Australia and New Zealand Ltd (I.C.I.A.N.Z.).

The conventions in regard to the use of the terms production and supply in the civil series of this history require some explanation. Hasluck[3] says:

> Production, in its simplest sense, covers the growing of crops, the winning of ores, timber and fuel, the generation of power, the processing of materials, the manufacture of commodities, implements, machines, weapons and munitions. It also means the bringing together of the men and materials, the machines and power in the right place in order that they may produce. . . . Supply, in its simplest sense, covers the arrangements by which any kind of product is obtained and delivered at the point where it is to be used. It covers both the products of the nation's own industry and the products of other nations. . . . It involves the placing of orders, arrangements for delivery, storage and paying of bills.

Although the terms supply and production are used to describe a great number of inter-related activities, the emphasis in this volume will be on production and the way in which it was influenced by science and technology. It is not intended to give a detailed account of the activities of all the directorates in the Department of Munitions, since a number were concerned with questions of finance, control and supply which are fully described in the other volumes of this series.[4] Only so much of the story of supply and administration will be told as is necessary to see production in relation to defence.

The degree of industrialisation of which a country was capable and upon which its defensive strength so greatly depended, was to a large

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[1] For help in writing this chapter I am particularly grateful to Mr Neville Wills, the B.H.P. Company's historian, and to Mr George Bishop.

[2] Essential materials controlled were: (*a*) ferrous metals—iron and steel sheets, plates, strips, etc; (*b*) non-ferrous metals—copper alloys (angles, bars, pipes, etc); (*c*) alloys of molybdenum, tungsten, nickel, platinum, etc; (*d*) a large range of industrial chemicals. Control was exercised by licence, and the use of a material could be prohibited either for all purposes or for stated purposes.

[3] P. Hasluck, *The Government and the People 1939-41*, in this series, p. 449.

[4] See Hasluck, and also S. J. Butlin, *War Economy* (in two volumes).

extent determined by the abundance of its supplies of raw materials, among which none stood higher in importance than metals, fuels and heavy chemicals. Of the forty-odd metals[5] in commercial use iron and steel easily overshadowed all others, making up about 90 per cent of the total consumption. This was the reason for the statement sometimes made that the ability of a country to make war was roughly proportional to its capacity to produce steel. In the years 1939-45 about 90 per cent of Australia's total output of iron and steel, amounting to 7,559,000 tons of pig iron and 8,477,000 tons of steel ingots respectively, was used for purposes of war.

Efforts to set up an iron industry had been made at Mittagong, New South Wales, as early as 1848, but nothing had come of them. The first steel industry of any significance was developed at Lithgow, and by 1912 it had, as already related, grown sufficiently to induce the Commonwealth Government to erect a Small Arms Factory in its neighbourhood.

In 1911 the B.H.P. brought to Australia an American steel expert, Mr David Baker, to give advice about establishing a new steel industry. Baker reported that adequate supplies of suitable raw materials were available but in three widely separated regions: unusually rich iron ore at Iron Knob near the port of Hummock Hill[6] on the western shore of Spencer's Gulf, South Australia, suitable coking coal in Newcastle, New South Wales, and a sufficiently pure limestone at Wardang Island (S.A.). Providentially, all three were conveniently close to tide water, a circumstance which did much to ensure the economic well-being of the future industry.[7] Since in those days it required about three tons and a half of coal and one ton and a half of iron ore to make a ton of steel, it was clearly advantageous to bring ore to coal, and it was mainly for this reason that Baker recommended the industry be established at Port Waratah, Newcastle. Swamp lands in this vicinity were reclaimed, and when, on 9th March 1915, the first blast furnace was blown in by a small team of skilled American steelworkers assisted by Australians they had trained, and directed by Baker, who was now manager of the steelworks, the foundations were laid of an industry destined to have a profound influence on Australia's general development and her powers of defence. From the beginning, the organisation and technological practices of the Newcastle steelworks bore the imprint of American influence.

Greatly stimulated by the first world war—though it did not contribute much by way of munitions—the Newcastle industry attained an output from its two blast furnaces and seven open-hearth furnaces of about 200,000 tons of steel a year, which enabled it to provide rails for the East-West Transcontinental Railway in Australia and for the Western Front in France, plates for the Australian shipbuilding industry, and steel for

[5] There were about 8,000 alloys in commercial use.

[6] Later known as Whyalla. Leases covering this deposit had been taken out by the B.H.P. some years before when they began exploring the deposit for ironstone fluxes needed for smelting operations at Port Pirie.

[7] Neville Wills, "Economic Development of the Australian Iron and Steel Industry".

the United Kingdom, all under conditions which, in so far as they involved freedom from oversea competition, were economically favourable.

This breathing space for the industry did not long outlast the war. The next few years saw a determined struggle on the part of the Newcastle steel industry to meet the rising flood of oversea competition. In spite of government encouragement in the form of a protective tariff, and of steps to improve efficiency and increase local consumption by encouraging the development of associated fabricating industries such as those based on black iron sheets, corrugated galvanised sheets, wire, wire rope, netting and nails, the Australian steel industry came close to economic disaster more than once during the next ten years. Its salvation on those occasions lay in the fact that B.H.P. had other assets upon which to draw.[8]

In spite of many adverse circumstances, B.H.P. steadily pursued its policy of expansion and technical improvement, extending its ownership backwards to raw materials by acquiring three large collieries and a fleet of freighters for shipping ore, and forwards by reaching agreements with the fabricating industries.[9] Keeping well ahead of Australia's demand for steel, the company concentrated during the twenties on making the units of the industry as large as possible with bigger-than-average blast furnaces and open hearths. Modern electrical generators, providing power to operate rolling mills and other machinery throughout the plant, were installed. The Newcastle steel industry gradually became one of the most highly integrated and self-contained in the world.

The company's wisdom in controlling its own sources of coal supply may be seen in the fact that the Newcastle works at that time used more than 750,000 tons a year, the greater part of which went into the production of metallurgical coke. Efficient use of coal and recovery of the by-products of coking was a crucial factor in the economy of a steel plant. Replacement of the original Semet Solvay by-product ovens in 1930 by the much more efficient Willputte regenerative coke ovens was an important step in bringing the industry up to date. The weekly output of these ovens (at a time when they were consuming 17,000 tons of coal a week) was:

11,000 tons of metallurgical coke;
190,000,000 cubic feet of coal gas (enough to supply a city of 1,000,000 inhabitants for a week);
190 tons of ammonium sulphate;
40,000 gallons of benzol, toluol, solvent naphtha;
120,000 gallons of tar.

Some of the coal-gas was used to fire the coke ovens; the remainder was used in the works for a number of purposes.

An important feature of the new ovens was that they required for their own heating only 40 per cent of the coal gas they produced, as compared

[8] Essington Lewis, "The Importance of the Iron and Steel Industry to Australia". Joseph Fisher Lecture in Commerce, Univ of Adelaide, published at the Hassell Press (1948).

[9] B.H.P. became associated with Lysaght Bros (Aust) Pty Ltd 1929; Vickers-C'wealth Steel Products (later C'wealth Steel Co) 1929; Rylands Bros (Aust) Pty Ltd 1925; Stewarts and Lloyds (Aust) Pty Ltd 1929; Aust Wire Ropes Pty Ltd 1923; Titan Nail and Wire Co Ltd 1933.

with 60 per cent used by the older type of oven; in addition they gave higher output and improved recovery of other by-products. Fuel economy was achieved by other means as well: by faster and better methods of handling material to and from furnaces and ovens, and by improved designs for burners and regenerators. Much was achieved purely by methods of good housekeeping, or "by chasing waste as the good housewife chases dirt".[1] The net result over the years was to reduce the amount of coal needed to produce a ton of steel from three tons and a half in 1915 to about one and a half in 1932. These economies did much to help the steel industry weather the world depression.

Important developments took place in other industries of the Newcastle area. In 1935 Vickers-Commonwealth Steel Products Ltd, a subsidiary of B.H.P., became known as the Commonwealth Steel Company Ltd. About this time the company began manufacturing alloy steels (mainly of the stainless and heat-resisting varieties). Stewarts and Lloyds, a branch of the English company and an associated company of B.H.P., in 1934 made a notable contribution to the development of the steel industry by introducing the manufacture of butt-welded tubing.[2]

While these changes were taking place at Newcastle a new steel industry was coming into being at Port Kembla, N.S.W. The Lithgow industry[3] had, during the twenties, been encountering greater and greater difficulties, owing partly to the exhaustion of the easily-accessible iron ores in its vicinity but mainly to rising costs of transporting both raw materials and finished products. The directors of the Lithgow industry realised that if it was to survive in competition with Newcastle it would have to leave the Lithgow valley for a location near tidewater. They chose Port Kembla, and then contracted with a Chicago engineering firm (Freyn) for the design and construction of a blast furnace with a much greater capacity than any at Newcastle. This had barely been completed when a merger was arranged with three well-known British and Australian firms[4] to form a new company, Australian Iron and Steel Ltd. Using iron ore from Whyalla, South Australia, limestone from Marulan, New South Wales, and local coal, this furnace, the largest of its kind in the British Commonwealth, began producing pig iron in August 1928 at the rate of 800 tons a day. In the early days of its operation the Port Kembla steel industry was seriously unbalanced, lacking by-product coke ovens and sufficient open-hearth steel-making furnaces, but by 1939 this had to a large extent been rectified.

The early life of Australian Iron and Steel coincided with the economic depression and it laboured under serious disadvantages, from which it was rescued only by becoming a subsidiary of B.H.P. Consolidation of the

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[1] J. D. Norgard and W. H. Brooke, "Coal Utilisation, Modern Steel Works Practice", *Proceeding of the A/sian Institute of Mining and Metallurgy*, New Series No 145 (1947), p. 255.

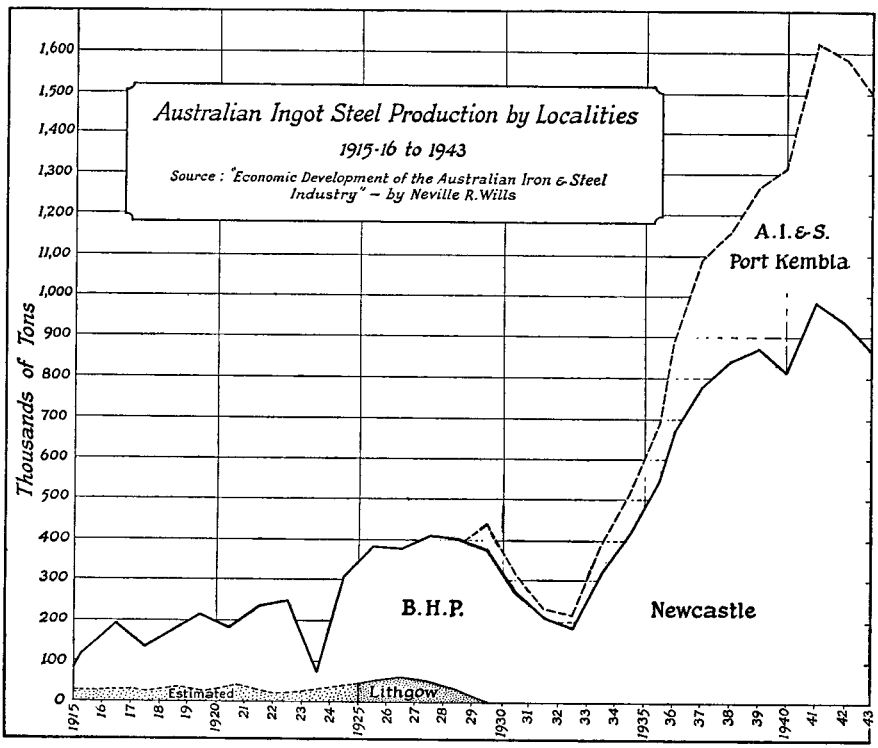
[2] A. N. Hamilton, "Tube making in Australia", *Proceedings of the Institute of Mining and Metallurgy*, No 99 (1935), p. 1.

[3] Hoskins Iron and Steel Ltd, which had been operating since 1900.

[4] Dorman, Long & Co Ltd, and Baldwins Ltd of England, and Howard Smith Ltd of Australia.

two main steel industries of Australia took place in October 1935, but the industry at Port Kembla retained the name of Australian Iron and Steel.

In the same year decisions were taken that were to have an important influence on the immediate future policy of the steel industry. During a tour abroad in 1934 Mr Essington Lewis became convinced from what he saw in Germany and Japan that war with these countries was almost inevitable. In his thinking about the needs of defence Lewis was well ahead of contemporary public opinion in Australia, which then as in most democracies, occupied itself mainly with the problems attending the recovery from the economic depression. On returning from Europe he and the Chairman of the Board of Directors of B.H.P., Mr Darling,[5] set about preparing the Australian steel industry to meet the demands that war might make upon it. It is difficult to say how far the rapid rise in the industry from its very low ebb during the depression was due to purely



economic factors and how far it was the result of a deliberate policy aimed at self-sufficiency. The upward trend had begun before 1935. One thing seems certain: without the extraordinary expansion that took place after 1935 Australia could not have met the industrial challenge of the

[5] H. G. Darling. Chairman, B.H.P. Ltd, 1922-50. Of Melbourne; b. Adelaide, 9 Jun 1885. Died 26 Jan 1950.

second world war as successfully as she did. Large stocks of iron ore, limestone and other raw materials vital to the steel industry were built up at Newcastle—a policy that was to pay good dividends when war put a great strain on the resources of coastal shipping. In spite of these efforts, stocks of iron ore were not sufficient during the war to prevent the need for reopening the New South Wales iron ore deposits.

From 1935 onwards steel-making capacity at Newcastle was rapidly increased by the addition of an open-hearth furnace each year for three years. Extensive additions were made in coke ovens, machine shops and rolling mills; one of the most important steps towards increasing the efficiency of the early stages of steel fabrication was the electrification of the heavy rolling mills, begun in the early thirties but not completed until 1940.

Important developments took place in other industries in the Newcastle area. In 1935 Vickers-Commonwealth Steel Products Ltd became a subsidiary of the B.H.P., changing its name in the process to the Commonwealth Steel Company. In the following year the company initiated a new phase of the Australian industry by manufacturing alloy steels, mainly in the form of castings and forgings of stainless and heat-resisting varieties. Later, plans were made for the rolling of special steels.

Stewarts and Lloyds (Australia) Pty Ltd, a branch of the English company and an associated company of the B.H.P., having established the process for making butt-welded tubing in 1934, decided in 1936 to install a push-bench for producing seamless tubing, an innovation that was to play an important part in the manufacture of shell bodies.

The plant at Port Kembla was also enlarged, the most notable addition being a blast furnace with a capacity of 1,000 tons of pig iron a day, which was blown in in May 1938. Earlier the same year a coke-oven and by-products unit came into operation. Considerable progress had also been made with the mechanisation of three South Coast coal mines owned by B.H.P. While the output of pig iron from Newcastle's three blast furnaces was only slightly greater than that of the two larger furnaces at Port Kembla, the production of steel at Newcastle was considerably greater because of the greater number of its open-hearth furnaces. Port Kembla, on the other hand, possessed newer and heavier rolling equipment and in some respects the two works were complementary.

The suggestion had been made in 1937 that B.H.P. might assist in the development of South Australian industry through an extension of its activities to the State from which for many years it had drawn its entire supplies of iron ores. Whyalla, the port from which these ores were shipped, was a possible site for a new steel industry since the efficiency in utilisation of coke for smelting had now advanced to a point where it was economically feasible to bring coal to ore. Continuity of ore supply had been guaranteed by the 1937 Indenture Act,[6] under which the South Australian

[6] *Parliamentary Papers 56.* Parliament of S Aust. Evidence before Select Commission of the House of Assembly on the B.H.P. Indenture Bill 1937, S Aust Blue Book.

Government agreed to extend the company's iron ore leases at Middleback for a period of 50 years.

If any further stimulus was required to set the industry in motion, it was supplied by the imminence of war. Decentralisation of iron making had much to recommend it from the point of view of defence. As happened 24 years earlier at Newcastle, the actual outbreak of hostilities speeded up the whole project. Whyalla, the site chosen, had for many years been developed as an ore shipping port, but its growth was greatly accelerated in 1937 after a decision to erect a blast furnace there. The major units of the iron and steel industry in operation at the end of 1939 are shown in the accompanying chart.

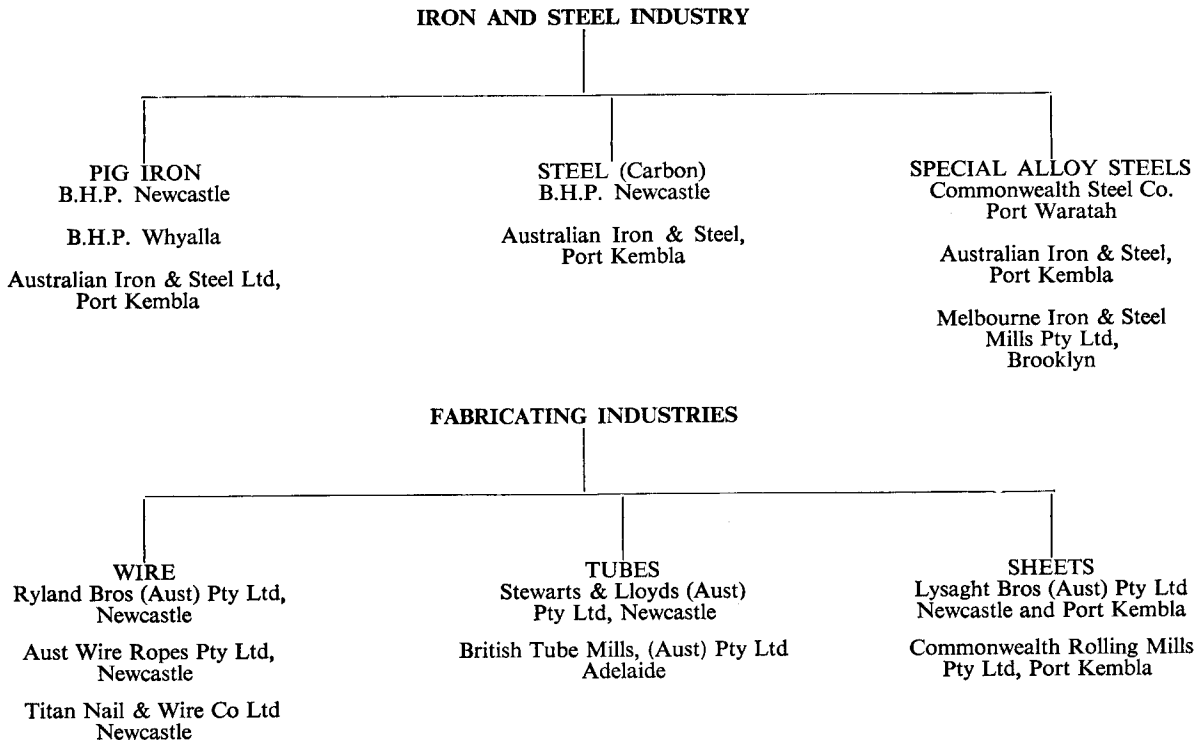
By their unswerving pursuit of efficiency and their policy of ruthlessly scrapping obsolescent plant and replacing it with the most up-to-date available, and by exploiting to the utmost the economic advantages inherent in the supply of raw materials, Lewis and Darling had on the outbreak of war brought the Australian steel industry to the stage where it could make steel cheaper than any other producer in the world. With a capacity of about 1,000,000 tons of ingot steel a year—double that of 1935—the Newcastle Steelworks became one of the largest in the British Commonwealth.[7] Australia was now able to provide most of its own requirements of steel for the agricultural machinery, motor-body building, aircraft, chemical, shipbuilding and heavy engineering industries. The B.H.P. not only supplied the great bulk of the nation's steel but also operated workshops designed principally to meet the needs of its own construction and maintenance programs, which were capable of undertaking a wide range of jobs including the building of engines and the construction of bridges. Machines in these workshops stood ready for the manufacture of guns, gun ammunition and other munitions.

On the whole the steel industry, the corner-stone of the country's industrial structure, was more nearly ready to meet the shocks and stresses of war than any other. By way of more direct preparations, large stocks of iron ore, limestone and other vital raw materials, especially those obtained from overseas, were built up at Newcastle. As early as 1936, and by arrangement with the Department of Defence, B.H.P. sent technical officers to the Ordnance Factory at Maribyrnong to study methods of shell manufacture. Some months before the war, shell bodies for 3-inch anti-aircraft and 18-pounder guns were being turned out at the rate of 3,500 a week which, although negligible by comparison with later efforts, meant that the company had gained experience that proved to be of the greatest value when large-scale production was called for. B.H.P. was the first commercial organisation to enter the field of munitions production.

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[7] Australia stood fifth in the list of countries in terms of steel production per head, and was 13th in terms of total production:

U.S.A.	0.601	tons	per	head	of	population	Britain	0.300	tons	per	head	of population
Belgium	0.445	"	"	"	"	"	Australia	0.246	"	"	"	"
Germany	0.306	"	"	"	"	"	Canada	0.229	"	"	"	"


IRON AND STEEL INDUSTRY
PIG IRON
B.H.P. Newcastle
B.H.P. Whyalla
Australian Iron & Steel Ltd, Port Kembla
STEEL (Carbon)
B.H.P. Newcastle
Australian Iron & Steel, Port Kembla
SPECIAL ALLOY STEELS
Commonwealth Steel Co. Port Waratah
Australian Iron & Steel, Port Kembla
Melbourne Iron & Steel Mills Pty Ltd, Brooklyn
FABRICATING INDUSTRIES
WIRE
Ryland Bros (Aust) Pty Ltd, Newcastle
Aust Wire Ropes Pty Ltd, Newcastle
Titan Nail & Wire Co Ltd Newcastle
TUBES
Stewarts & Lloyds (Aust) Pty Ltd, Newcastle
British Tube Mills, (Aust) Pty Ltd Adelaide
SHEETS
Lysaght Bros (Aust) Pty Ltd Newcastle and Port Kembla
Commonwealth Rolling Mills Pty Ltd, Port Kembla

In order to make even the briefest survey of the activities of the steel industry in Australia during the war it will be necessary to consider them in three main sections:[8]

1. the manufacture of raw materials for munitions industries—steels of many kinds for tools, for guns, ammunition, tanks, torpedoes and aircraft;
2. the manufacture of machine tools and forgings for guns and ammunition;
3. the fabrication of iron and steel into sheets, wires and tubes for military purposes other than weapons.

This is a very rough classification and there is a good deal of overlapping between (2) and (3). From this point on the main concern will be with the steel industry as a source of raw materials for munitions.

Though much had been done in the way of preparing the steel industry for the emergency of war, a great deal remained to be done after war broke out. No one could have predicted exactly what the demands on it would be. The completion at Whyalla of a sixth blast furnace, which began operation in May 1941, was a major step in the wartime expansion of the industry. It brought the total capacity for producing pig iron up to 1,764,000 tons a year; the maximum output of 1,543,973 tons was achieved in 1941, but thereafter, owing to the inevitable decline in manpower available for industry, and, after 1943, the decline in demand, production fell. The output of iron and steel from 1938 to 1944 is shown in the accompanying table. To keep pace with the increased output of pig iron it was necessary to build more open-hearth furnaces for making steel: one was built at the Newcastle Steelworks, and two at the works of Australian Iron and Steel at Port Kembla. This step did not of itself guarantee an increased supply of steel. There remained the problem of obtaining the raw materials used in the conversion of pig iron to steel.

	Pig iron (tons)	Ingot steel (tons)
1938-39 . .	1,104,605	1,171,787
1940-41 . .	1,475,707	1,647,108
1941-42 . .	1,557,641	1,699,795
1942-43 . .	1,399,306	1,632,825
1943-44 . .	1,305,357	1,527,564

One of the few weaknesses of the Australian steel industry before the war (as far as its self-sufficiency was concerned) lay in its reliance on imports for all ferro alloys. These alloys of iron with fairly large proportions of such elements as silicon, manganese, zirconium, tungsten or chromium, find two principal uses in the steel industry: (*a*) in making ordinary large-tonnage carbon steels, and (*b*) in making special steels, or alloy steels. The first use depends on the ability of some metals (manganese, silicon, aluminium and zirconium) to remove oxygen and sulphur from steel—to act as deoxidisers. For these purposes ferro silicon and ferro manganese are most effective; without an adequate supply of both these alloys the

[8] Much of the information for this section came from D. O. Morris, "A Review of Wartime Activities of the Newcastle Steel Plant of B.H.P. and its Associated and Subsidiary Industries", *Proceedings of the Asian Institute of Mining and Metallurgy*, New Series No. 146 (1947).

whole of the steel industry, and with it the munitions program, would have been jeopardised. The ferro alloys used in making special steels were scarcely less important. That they had not previously been made in Australia was due more to economic than to technical difficulties. Most ferro alloys were made in electric furnaces that consumed unsually large amounts of electric power. For this reason their manufacture had been concentrated in countries endowed with ample supplies of cheap hydro-electric power: Canada, Scandinavia, the United States and Japan. Foreseeing the dangers of a failure of the supply of ferro alloys, B.H.P. began negotiations in 1939 with an American firm specialising in their manufacture for information, drawings and equipment. This was none too soon. Installation of electric furnaces at the Newcastle steelworks was pushed ahead vigorously and the production of ferro alloys was begun towards the end of 1940. The manufacture of ferro alloys brought with it problems of power supply. In order to avoid drawing on supplies of power provided by municipal authorities, which were already heavily taxed, the power station at the steelworks was extended. Operating mainly on blast-furnace gas as a fuel, this station, which also acted as a reserve against the possible destruction of the municipal station, provided all the electric power used throughout the steelworks, including the ferro alloy plant.

Two separate plants were built: one housing three large electric furnaces of the submerged-arc type with a nominal power input of 4,500 kilowatts, for making alloys required in large tonnages (such as ferro silicon and ferro manganese); and a second for alloys required in only small amounts or for alloys whose preparation was carried out by means other than the electric furnace.

Alloys of two metals were frequently made by first liquefying the metal with the higher melting point and then gradually adding the second metal in the solid state so that it dissolved in the first. Many of the metals used in ferro alloys were not easy to extract from their ores, and moreover had melting points that were too high for alloying with iron in the way just described. It was more convenient not to isolate the alloying element as a separate step, but to release it from one of its compounds by high-temperature reduction with coke, and simultaneously to allow it to alloy with molten iron. Ferro silicon, for example, was made by melting a mixture of scrap iron, quartzite (silicon dioxide) and coke in an electric furnace, when the silicon liberated by the reduction of the quartz immediately alloyed with the molten iron.

Some of the raw materials for ferro alloys had to be imported; for instance, manganese ore from India and South Africa, and chromium from Rhodesia or New Caledonia. No adequate deposits of these minerals had then been found in Australia.[1] In spite of the fact that stocks had been built up before the war, Australia became seriously short of some ores, especially nickel, and it was only by improvisation and considerable ingenuity on the part of metallurgists that the situation was saved. The extent

[1] A small amount of manganese ore was produced in W. Aust.

and variety of the wartime production of ferro alloys are shown in the accompanying table.

Ferro silicon, 50% Silicon	29,919	tons
„ „ 75% Silicon	323	„
Ferro chromium, High carbon	6,510	„
„ „ Low carbon	1,503	„
Ferro zirconium (zircon sand from Byron Bay)	463	„
Silico manganese	1,808	„
Ferro manganese, High carbon	1,014	„
„ „ Low carbon	11	„
Chromium silicide, 2% Carbon	255	„
„ „ 1% „	108	„
„ „ 0.2% „	322	„
„ „ 0.1% „	1,586	„

The output of ferro alloys required only in relatively small amounts—those whose production was given in pounds rather than in tons—was as follows:

Ferro molybdenum	45,914 lb
Ferro titanium[2]	348,504 lb
Ferro vanadium	2,240 lb
Ferro tungsten	476,302 lb

Owing to the smallness of the quantities required and the extremely high temperature needed to effect reduction, it was found more convenient to make the last three by the alumino-thermic method. A mixture of the oxide of the alloying element—titanium dioxide, for example—finely powdered aluminium and scrap iron was placed in conical steel pots lined with calcined magnesite and fired by magnesium. The heat generated by the reaction between the titanium dioxide and the aluminium was sufficient to melt both the titanium liberated by the reduction and the scrap iron. The only essential difference between this and the electric-furnace method was in the means used to produce the high temperature necessary to melt the alloying metals. In practice it was found that the alumino-thermic method caused smaller losses of material through volatilisation. Very finely powdered aluminium used in these alumino-thermic reductions was made by "atomising" a stream of molten scrap aluminium in an air blast.[3] Aluminium alloys required by the Australian Aluminium Company, Ltd—aluminium-titanium used for refining the grain structure of duralumin alloys for aircraft construction, and aluminium-manganese alloys required as hardening additions for casting magnesium—were made by the same method of reduction.

Of the large number of different steels used in commerce, more than 100 were made at Newcastle. A broad general classification would divide them into two main classes: ordinary high-carbon steels, and alloy steels. Alloy steels contained, in addition to carbon, quantities of such elements as chromium, molybdenum, nickel, manganese, tungsten and silicon intro-

[2] Titanium dioxide for this alloy came from the beach sands of northern N.S.W.

[3] Ingot aluminium from the Department of Munitions was used after supplies of scrap had been exhausted.

duced into the steel in the form of ferro alloys. The physical properties of steel are greatly influenced by the nature and amount of alloying elements: manganese imparts toughness; tungsten hardness, which is retained at high temperatures; chromium and nickel strength and ductility and a tendency to resist corrosion; zirconium and molybdenum endow steel with great hardness combined with toughness. The list could be greatly lengthened and elaborated but it will suffice to show the importance of alloying elements in exploiting the great versatility of steel. Most of the carbon steels were made in the open-hearth furnaces of the Newcastle Steelworks and of the Australian Iron and Steel Company at Port Kembla, but alloy steels were produced in other more specialised plants. The maximum output of ordinary carbon (or tonnage) steel was achieved in 1941 when 20 open-hearth furnaces yielded 1,624,936 ingot tons; average yearly production was 1,412,913 tons, making a total for the war years of 8,477,478 tons. The output of special alloy steels was of course much lower, averaging about 65,000 tons a year or a total of 390,000 tons.

The manufacture of alloy steels had been pioneered in Australia by Commonwealth Steel Products Ltd (later known as the Commonwealth Steel Company) which built the first electric arc furnace for the purpose in 1919. At first the company, whose technical practices were based extensively on those of the English firm of Firth Vickers, concentrated on the manufacture of stainless and heat-resisting steels, and by means of its close contacts with leading oversea makers of special steels was able to keep abreast of modern developments in alloy steels and to build up an organisation possessed of technical knowledge not available elsewhere in Australia.

The Committee of Empire Defence which met in London in 1937 (sitting as a separate committee of the Imperial Defence Committee) paid particular attention to the question of Australia's self-sufficiency in the production of special steels. The committee was well aware that an interruption to the supplies of those kinds of special steel not made in Australia—especially tool steels—could have a disastrous effect upon the country's industrial development. The Secondary Industries Research and Testing Committee sounded a similar warning. If for any reason, it said, the supply of tool steels was cut off, the greater part of the engineering industry in the Commonwealth would be brought to a standstill. Dependence on outside sources for the kinds of steel indispensable for high-speed cutting tools and for forges and stamping presses made the defence industries vulnerable indeed.[4] Shortly after the discussions in London and the appearance of the report of the Research and Testing Committee, the Commonwealth Steel Company made its first batches of high-speed (tool) steel.

In addition to tool steels there were others equally important for defence: alloy steels for gun forgings, armour-piercing shells, armour plate, aero-engines and torpedoes, and for chemical industry.

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[4] Tool steels were of two main kinds: carbon steels and alloy steels. Steels in the latter group, containing as much as 20 per cent of tungsten, were specially important.

Plans were therefore drawn up by the Commonwealth Steel Company for the extension of its works by the installation of additional furnaces—one open hearth, one electric arc and two high-frequency induction—for making special steels, together with large and fully equipped bloom, bar and sheet rolling mills. Construction of the massive, complicated rolling machines and the erection of a very large building to accommodate them was begun in April 1939 and completed at high speed. The first sections of the new extension, known as the Special Steel Plant, to come into operation were the rolling mills, in August 1940; the electric furnace was completed in February 1941, but it was not until twelve months later that the large 50-ton open-hearth furnace was ready for operation. Three shifts a day, seven days a week, was the rule in almost every section of the alloy-steelworks.

The alloy-steel plant required a large force of skilled operators, many of whom underwent additional training in handling the new materials. The sources from which employees of this type could be drawn were, by comparison with highly-industrialised countries overseas, distinctly limited, and the successful surmounting of this obstacle was by no means the least of the industry's achievements. Similarly, semi-skilled and unskilled men were needed in large numbers, and the rapidity of development may be judged from the fact that the labour force increased by some 500 per cent during the war years. Workers were drawn from every walk of life—from retail stores, delivery waggons, sheep stations and shearing sheds. Some recruits came from small businesses rendered uneconomic by war, others from clerical and similar occupations. Most employees in this rapidly-growing force had to be trained for their various jobs; all had to be trained in safe working because of the many hazards which were inseparable from the operation of a steelworks and to which they were totally unaccustomed.

This plant, together with smaller ones at Port Kembla and in Melbourne (Melbourne Iron and Steel Mills Pty Ltd) combined to make Australia to all intents and purposes self-sufficient in regard to special steels. The uses of these steels were legion: for munitions, where they were indispensable in making guns and small arms; in food factories, textile mills, chemical plants, aircraft, ships, transport vehicles, hospitals, and in precision instruments. Only a few of the 140 different special steels, many of which were made in Australia for the first time, can be mentioned here.

The importance of tool steels lay in the fact that they were essential to the shaping of other steels. High-speed steels contained as their most important added element, tungsten or cobalt in proportions varying with the purpose for which the steel was intended. Possessing great hardness even at high temperatures, these steels were used mainly in lathe tools and shaper tools, milling cutters, twist drills and reamers. They made it possible to construct plant, machines and equipment of all kinds. In the same category were the hot-die steels used in making the dies for drop-forging and the special tungsten steels used in punches and chisels.

Until 1939 the knowledge of how to make bullet-proof steel and armour plate was confined—in the British Commonwealth at least—almost exclusively to a few British firms, the best known of which was Hadfields Ltd, who specialised in the production of steels of this kind. Just before the war, Australian metallurgists gained some knowledge of processing the famous Hadfield "Resista", a complex nickel-chrome-molybdenum steel formulated to meet the requirements of the British Army Ordnance. Small quantities of this steel had been made by the Commonwealth Steel Company for Bren Gun carriers and other armoured fighting vehicles.

Hadfield's "Resista", because it contained substantial percentages of nickel, molybdenum and chromium, was a fairly intractable steel to form and shape. In fact the only satisfactory way of doing this was to anneal the steel after it had been rolled into sheets. This put the steel into such a condition that the operations of drilling, planing and slotting could be easily carried out. When these operations had been completed, the shaped parts were hardened in oil and tempered to yield physical properties combining maximum hardness and toughness. After the steel had been finally hardened and tempered, several pieces were taken at random from each batch and subjected to a ballistic test, the nature of which varied according to the thickness of the plate. If a piece failed to withstand the test, the whole batch was likely to be condemned and all the work and money put into it entirely wasted.

In 1940, when Ordnance Production Directorate's extensive requirements of bullet-proof plate were made known to Essington Lewis, his chief metallurgical adviser, Mr Clark,[5] pointed out that there was insufficient nickel, chromium and molybdenum in the country to permit the use of "Resista" steel, and it was imperative to find a substitute. Mr Bishop,[6] who was coopted from the B.H.P. by the directorate to tackle the problem, was told that a substitute bullet-proof plate was required in thousands of tons, and that it must not only meet the normal ballistic tests of the British Army, but also be capable of being welded. This last provision was made because it had been found that riveted armour vehicles under attack, particularly from ball ammunition, were vulnerable at the rivets, which were eroded by what was thought to be vapourised lead. Crews of riveted vehicles were often severely burned by lead vapour. The proposal to weld armour plate was made with the idea of eliminating this hazard and at the same time of expediting manufacture generally.

"Resista" steel owed its extreme toughness to the presence of nickel which caused it to assume a fine-grained structure. Bishop therefore directed his attention to finding another metal which would produce the same effect. The conventional method of inducing a fine-grained steel was to add aluminium. Its use for bullet-proof plate was considered un-

[5] D. Clark, Chief Metallurgist, C'wealth Steel Co Ltd, 1926-41, 1944-48; Metallurgical Adviser, Ministry of Munitions, 1941-44; Chief Research Officer C'wealth Steel, 1949-52. Of Newcastle; b. Glasgow, Scotland, 25 Jan 1883.

[6] G. H. Bishop. Successively Service Superintendent, B.H.P. Ltd, Steel Superintendent, Asst Production Superintendent, Production Superintendent, Assistant Manager. Of Newcastle, NSW; b. England, 29 Mar 1906.

desirable in view of the fact that it could, under certain circumstances, cause the formation of soft areas and certain types of non-metallic inclusion which because of their weakening effects were highly deleterious.

A second possibility was to use vanadium, but since ores of this metal could not be imported (none had been found in Australia) it also had to be ruled out. In the end it was decided to try zirconium, since the mineral zircon was indigenous to New South Wales and Queensland and its supply would therefore present no problem. To offset the absence of molybdenum which was also in short supply it was decided to add larger percentages than usual of chromium and manganese to confer depth hardness and at the same time to keep down the carbon content of the steel in order to make it reasonably weldable. In due course a composition based on the foregoing considerations was devised and a batch of 30 tons of steel was made in the "basic" open-hearth furnace of the steel foundry at the works of B.H.P., Newcastle. At this stage it was expected that the resulting steel would have to be subjected to the usual process of hardening and tempering, but it was hoped that the tedious business of annealing to facilitate machining, drilling and planing operations might be avoided. The intention was to eliminate these operations altogether by using profile oxy-acetylene torches for cutting the plates to shape and then assembling them by the process of welding.

The first ingots from the experimental batch were rolled into slabs and plates were examined. It was found that the steel in its "as rolled" condition was not only hard, as it would need to be if it were to satisfy a ballistic test, but was, most fortunately, also extraordinarily tough. "As rolled" plates were set up for proof testing and found to perform satisfactorily. It was thus evident that the steel had properties which rendered unnecessary any further heat treatment, and all efforts were directed towards its production.

Having pioneered the production of Australian bullet-proof steel, the B.H.P. now found that the extraordinary demand for armour plate greatly exceeded the company's rolling capacity for plates, and arrangements were therefore made with Lysaght's Newcastle Works Pty Ltd to undertake the rolling and fabrication of the finished plates from slabs produced on the B.H.P. Company's 28-inch mill.

At this stage it was evident that, in order to develop the bullet-resistant properties of the steel to the fullest extent in the wide range of sections required, and in order to cope with normal variations in composition, special rolling conditions and techniques for controlling the rate of cooling were necessary. After a period of intensive investigation under the direction of Mr Parry Okeden,[7] Manager of Lysaght's Works, and Mr. Hawkins,[8] Technical Superintendent, methods were evolved for the production of bullet-proof plate ranging in thickness from one sixth of an inch

[7] R. G. C. Parry Okeden. Chairman and Managing Director, Lysaght's Works Pty Ltd since 1940. B. Blandford, Eng, 25 Dec 1900.

[8] J. Hawkins. Technical Superintendent, Lysaght's Works Pty Ltd. Of Newcastle, NSW; b. Hillgrove, NSW, 16 Aug 1908.

to one inch and a quarter. An essential part of their process was that each plate, as part of the production-line processing, was subjected to a triple ballistic test, the marks of which were carried by the finished armoured vehicle and no doubt inspired its crew with confidence.

After having been tested, the plates were rapidly and accurately cut to shape by a series of oxy-acetylene profile machines and assembled in complete sets for each particular type of vehicle or piece of equipment for which they were designed. Sets were despatched to various centres in Sydney, Melbourne, Adelaide and Brisbane, where they were assembled by a method of fusion welding adapted to this particular type of steel.

Despite the many problems involved in the handling of the heavy plates in furnaces and rolling mills designed for much lighter work, some 23,780 tons of Australian bullet-proof plate was rolled by Lysaght's between 1940 and 1944. The plate was used principally for armouring large numbers of Bren gun carriers, mortar carriers, guns, light armoured cars and aircraft.

The chronic shortage of fuel with which the steel industry had to contend was a challenge to its engineers. In response notable advances were made in the use of blast-furnace gas in the various steel-making operations. Claims were made that improved methods of using blast-furnace gas brought about savings in coal consumption of about 40,000 tons a year in the Port Kembla Steelworks alone.[9]

In this condensed account of the steel industry, where the emphasis is of necessity on what was achieved rather than how it was achieved, it is difficult to avoid giving the impression that its activities consisted of an unbroken sequence of straightforward manufacture. In fact, of course, many obstacles presented themselves, and they were not always easily overcome; some were not overcome—at least during the war years. The production by the three major steel makers of more than 7,559,000 tons of pig iron and 8,477,000 tons of steel, the latter including 500,000 of alloy and other special quality steels, which often had to be made in plants that had not been designed for them, was in itself a major achievement. Difficulties and failures were inevitable in an undertaking of this magnitude, but whatever they were the steel industry never failed to supply the steel the munitions industries asked for. In an address during 1943 the Minister for Munitions, Mr Makin,[10] said: "I feel particularly fitted to speak of B.H.P's work. . . . Millions of tons of steel have been made available at prices below those paid by other countries. For munitions factories and the equipment of the fighting forces steel has been supplied at cost price."

Steel for war had to be of the highest quality. For this reason the proportion of the output used was smaller in war than in peace. Only the best portions of an ingot of steel were acceptable—the middle third of an ingot was used for the larger gun barrels and for the pressure

[9] See H. Escher, Developments in the Use of Blast-Furnace Gas at the Port Kembla Steel Works, *Journal of the Iron and Steel Institute*, Vol 156 (1947), p. 1.

[10] Hon N. J. O. Makin. MHR 1919-46 and since 1954. Minister for Navy and for Munitions 1941-46, for Aircraft Production 1945-46; Aust Ambassador to U.S.A. 1946-51. B. Petersham, NSW, 31 Mar 1889.

vessels of torpedoes; the remainder was discarded. Greater production of the necessary high-quality steel in wartime was therefore brought about not so much by increased efficiency in processing as by an increase in manpower, plant and steel-making capacity.

It was in the manufacture of steel for the young Australian aircraft industry that the steel manufacturers were put to their most exacting test. Steel for highly-stressed parts of aircraft needed to be as near perfection as it was humanly possible to make it. No steel was subjected to more exhaustive testing than that used in aero-engines. Early in the war chromium-molybdenum steels for aero-engines were made in the electric-arc furnaces of the Commonwealth Steel Company, but as the demand grew these supplies proved inadequate and the work was transferred to the larger, though less suitable, open-hearth furnaces at the Newcastle Steelworks. One of the principal difficulties was to make a "clean" steel —that is, one of the requisite homogeneity, free from cracks and blemishes and non-metallic inclusions. In order to learn how best to achieve this objective, Messrs Bishop and Stephenson[1] were sent to study the manufacturing details and standards of inspection at the works of the Bethlehem Steel Corporation in the United States. Much timely assistance was given to B.H.P. by this organisation and also by the North American Aviation Corporation.

Inspectors approved by the Aircraft Inspection Directorate were posted in the steelworks, and the different aircraft manufacturing authorities later carried out check inspections of aircraft steels on their own account. The magnetic flux method for detecting fine cracks and flaws in steel was extensively applied. Notwithstanding all efforts to ensure that only the best-quality steel reached the manufacturers, alarmingly high percentages of finished components were rejected. This represented a serious waste indeed. So much dissatisfaction among aircraft manufacturers arose from this cause that it became imperative to call in a third party to investigate the whole problem. An eminent authority on aircraft steels from Britain, Mr T. R. Middleton, of the English Steel Corporation, Sheffield, was consulted and asked by Lewis, as Director-General of Aircraft Production, to make a report.

Steel manufacturers had at first little real understanding of the standards of quality required by the aircraft industry, and to make matters worse the aircraft industry itself had in its early days little to offer in the way of guidance. To some extent it was a case of the blind leading the blind. Very high rates of rejection of components led to mutual recriminations: steel manufacturers accused aircraft authorities of demanding impossibly high standards, of inconsistency in their standards, and even of not knowing what they wanted; aircraft manufacturers countered by criticising the adequacy of inspections made in the steelworks. There were faults on both sides; neither system of inspection was free from shortcomings. Middleton was able to assure the steel industry that the aircraft manu-

[1] H. Stephenson. Metallurgist to Tullochs Ltd, and Hadfields to 1933; Steel Superintendent, C'wealth Steel, from 1933. Of Newcastle; b. Bradford, Eng, 22 Nov 1898.

facturers had not in general set the standards too high and that the majority of rejections of finished steel components were in fact fully justified.[2] What caused him a great deal of concern was the atmosphere of distrust between the inspection systems of the two industries. Apart from a few instances he found that no real effort was being made to establish a better understanding by close collaboration. Steel manufacturers were rarely given an opportunity to examine finished components which had been rejected on account of material defects. Middleton's advice was "that those responsible for metallurgical examination and inspection at the steel plants should take an opportunity of visiting aircraft plants . . . to develop a better understanding of the problems with which the aircraft manufacturers are faced".

Middleton examined steel at both works and satisfied himself that the majority of heats being manufactured in 1944 could be classified as "reasonably clean". At the conclusion of a report submitted in April 1945 he stated that although steel manufacturers had progressed very considerably towards satisfying the high standards of the aircraft industry, they had still not reached the stage where they could be regarded as completely "aircraft-steel-minded". He warned that satisfactory progress could not be expected unless a better understanding was developed between experts of the aircraft and the steel industries.

One of the most difficult of all steels to make and to fabricate was armour-piercing steel, a medium carbon-nickel chrome steel. With the help of some information on production techniques obtained from the Woolwich Arsenal in England the Commonwealth Steel Company began to build a special annexe for making armour-piercing shells in 1940.

The steel, made in electric furnaces of both the arc and induction type, was cast into specially-designed iron moulds. After solidification the cast, solid shell bodies were stripped from their moulds and toughened by annealing. The shells were then continuously heated under carefully controlled conditions and passed on to a 300-ton press where they were forged. The forgings were annealed, machined and finally hardened under carefully-controlled conditions of heating to give the necessary hardness gradient from the nose to the base. From this annexe came the first armour-piercing shells (6-inch and 4.7-inch shells for the navy) to be made in Australia. Their manufacture was considered to be one of the outstanding achievements of the steel industry, which had to a large extent been thrown on its own initiative in working out the details of an intrinsically difficult technical process.

In a similar annexe for producing smaller armour-piercing projectiles—25-pounder and 17-pounder shot (solid shell)—built by B.H.P. at the Newcastle works, the manufacturers displayed a good deal of initiative in devising methods of handling the steel. Much of the equipment used in forging, annealing and specialised heat treatment was of an original character and was completely designed, manufactured and installed by the

[2] T. R. Middleton, *Report on Steels of Australian Manufacture for use in Aircraft Construction*

company. Sufficient progress had been made by December 1941 to begin operations in a small way and to start with hardening of the shot—a vital part of the manufacturing process. Great difficulty was experienced in machining the resulting shot on account of the toughness of the steel. No one in the works had had any experience in the handling of such material in large quantities. To make matters worse the machines available were not rugged enough to stand up to the heavy work entailed. However, the effort was persisted with and proofing of the first mass-produced shot showed that it performed as well as shot that had been made by hand. This was an achievement of some merit, because hitherto in the British Commonwealth the manufacture of armour-piercing shot had been virtually a "made on the knee" process.

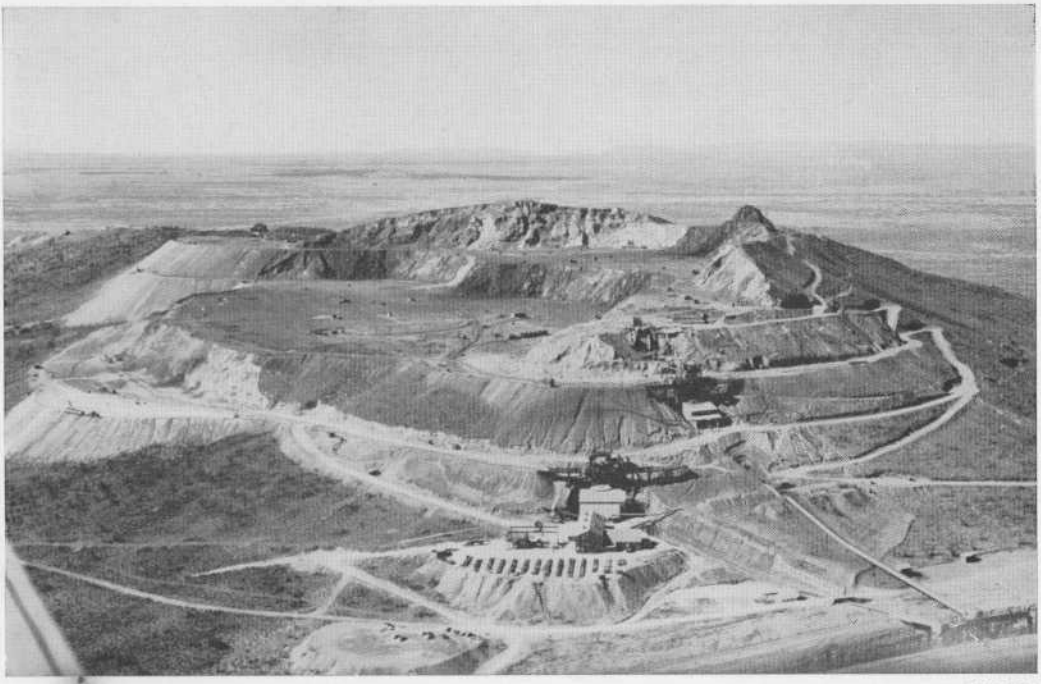
The Newcastle Steelworks made a wide variety of alloy steels: chrome-zirconium for bayonets, chrome-silicon for car and truck springs, nickel steels for aircraft and a special steel for the air vessels of torpedoes. Large quantities of the last steel, which as will be seen in a later chapter was one of the most closely specified of all, were also made by the Commonwealth Steel Company.

When the manufacture of protective steel helmets was first considered in Australia, no firm had had any experience with this material, but it was known that manganese steel would be difficult to roll. The production procedure was developed by Commonwealth Steel in conjunction with John Heine and Son Ltd of Sydney, who built the press in which all these pressings were made.

A similar material, an austenitic non-magnetic steel which had to be quenched from unusually high temperatures, was developed for use in the vicinity of ships' compasses. In all, some 2,000 tons of helmet steel and 700 tons of non-magnetic armour plate was produced as ingots and partly processed at Commonwealth Steel, and finally sheet-rolled at Lysaght's. About 2,000,000 helmets were made for Australia, New Zealand and India.

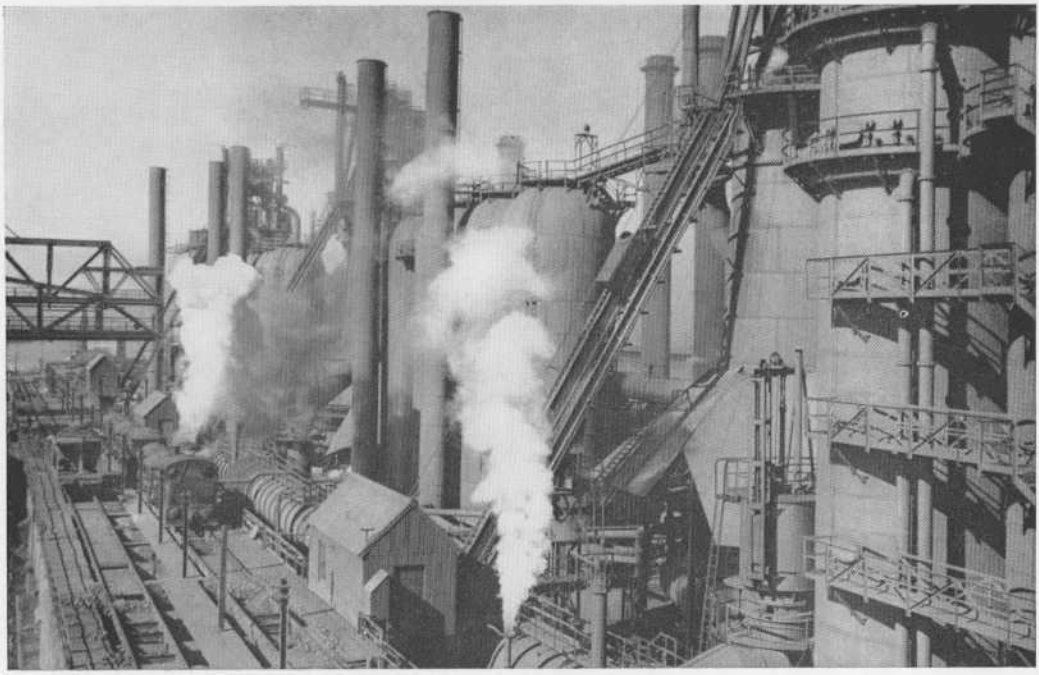
Besides supplying raw material for the munitions industry and maintaining and renewing its own plant, the steel industry also carried out a great deal of the fabrication of the steel, other than for ammunition, shaping some of it into rough castings and forgings and much of it into finished components: gun barrels and breech rings, and cylinders for aircraft engines. Large hollow cylinders capable of withstanding unusually high pressures were made by the Commonwealth Steel Company for chemical industry, particularly for the production of synthetic ammonia and methanol. Their manufacture involved the moulding and casting of an ingot mould weighing 76 tons, the largest ever attempted in the Commonwealth. In this mould were made the large ingots which were to be forged into cylinders capable of withstanding pressures of 525 atmospheres. Similar large cylinders were required for making the air vessels of torpedoes.

Many thousands of tools, gauges and fixtures needed for the manufacture of the cylinders of aero-engines, Bren guns and Owen guns were made in the toolroom of the Newcastle steelworks. In another chapter the



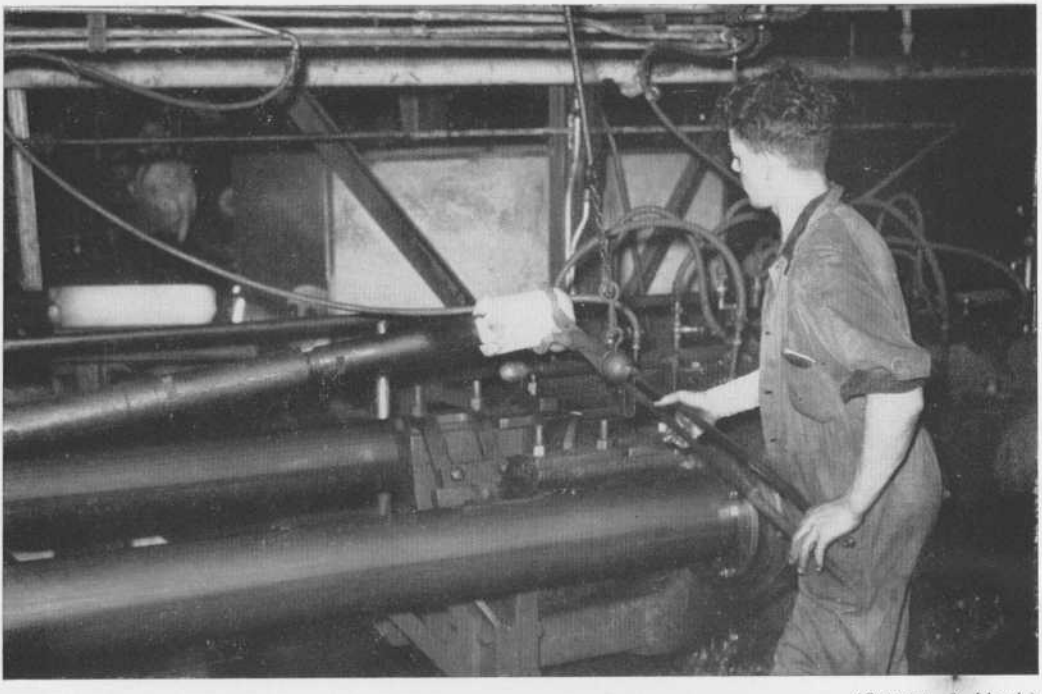
(*B.H.P.*)

The iron ore deposit at Iron Monarch, South Australia's main source of the Australian steel industry's requirements.



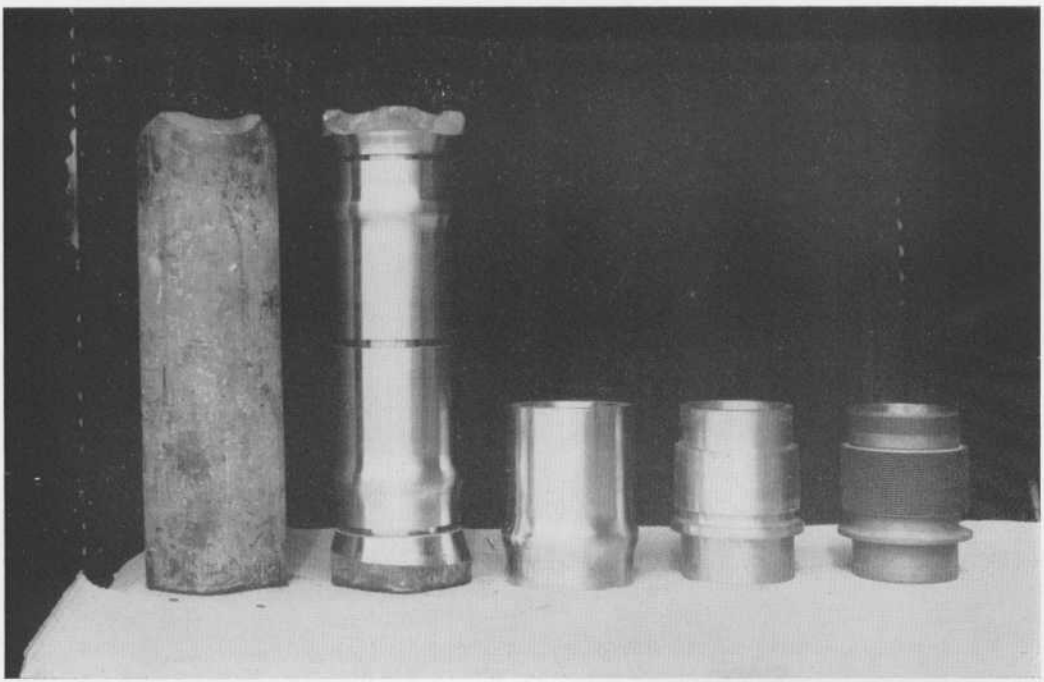
(*B.H.P.*)

The charging side of the blast furnace plant at the B.H.P. steelworks, Newcastle.



(Stewarts & Lloyds)

Shell forging plant. The bottle is sleeved over one of the forging machine mandrels.



(Stewarts & Lloyds)

Stages in the manufacture of an aircraft cylinder. Left to right: rough forging; rough machined forging, as removed from the lathe; individual rough machined cylinder barrel; barrel after second rough machining operation; the finished cylinder. Stewarts & Lloyds carried out the first four stages.

story will be told of how the machine shops of the steelworks helped to relieve what might otherwise have been a calamitous shortage of machine tools by making high-speed milling machines, planers, optical grinders, file-making machines and presses, ranging in capacity from a few hundred to 3,000 tons, for forging gun barrels and aircraft parts. From the machine shop came electric colliery locomotives, ships' boilers, marine engines and stern frames for ships. "No department of the steel works played a more vital role than the machine shop, and no order placed on it was beyond the ingenuity of its engineers and tradesmen. Its contribution to solving the technical problems of armament production cannot be rated too highly."[3]

The fabricating industries, concerned as they were with producing steel in three fundamental shapes—wire, tubes and sheets—contributed many articles that could not be classified as munitions in the narrow sense of that word but which were nevertheless essential for the purposes of war.

Wire drawing in Australia was pioneered by the Austral Nail Company which first began operating in Melbourne in 1911.[4] Some years later it transferred to Newcastle. In 1921 a second firm, Rylands Brothers of Warrington, England, decided to establish in Newcastle works for making wire netting. The two firms merged and in 1925 were taken over by B.H.P. By 1939 the wire mill of Rylands Brothers (Australia) Pty Ltd was one of the most complete of its kind in the British Commonwealth, and second only to the parent mill in England. It had, in fact, developed wire-drawing machines that operated at two and a half times the speeds then developed overseas. Every item of plant and machinery used was designed by the firm and in most instances manufactured in its own workshops. It is of interest to note in passing that this firm was, as far as can be discovered, the first in Australia to introduce the use of tungsten carbide in dies for wire drawing. Owing to its extreme hardness tungsten carbide enabled wire to be drawn at great speed and accuracy and with few interruptions since the die did not have to be repaired or replaced so often.

Each year from 1939 to 1945 more than 60,000 tons of steel of different kinds were converted into wire, 90 per cent of which was used, directly or indirectly, for munitions or essential national services. Millions of steel pickets and thousands of tons of barbed wire and netting found their way into the defences of the Middle East, Malaya, Netherlands East Indies, New Guinea and other islands of the Pacific.

Rylands made wire for mooring mines (11,000,000 feet), minesweeping (3,000,000 feet), for submarine and torpedo nets and harbour booms; wire for kites to prevent dive bombing of ships; 50,000,000 square yards of wire netting for use in camouflage and the construction of roads over sand or quagmire; rust-resisting wire for hospital beds, troopships and

[3] "Foundations of Steel—the B.H.P. Story" by Neville Wills; unpublished manuscript 1955.

[4] F. Jenks, "Steel Wire", *Journal of the Royal Aust Institute of Mining and Metallurgy*, New Series No. 145 (1947), p. 337.

field stretchers. Thousands of tons of wire were also made for reinforcing gun emplacements, for tracks, and bridges. They made wire for millions of bolts, rivets, nuts, screws, nails, buckles and clips. There was hardly a piece of equipment used by the Services that did not contain wire in some form or other.

Wire for springs formed an important part of Rylands' output. These ranged from heavy springs for tank shock absorbers to tiny steel springs for ammunition fuses. Fuse springs, ten thousand of which will fit into a large cigarette packet, are said to represent steel in its most costly form, enhanced to £750,000 a ton. Springs for aircraft engines—springs of the highest reliability—were important contributions to the aircraft industry.

An unusual kind of wire made only after considerable technical difficulties had been overcome, was the specially drawn core wire, consisting of a core of hardened steel sheathed with successive layers of lead and nickel, a structure used to give great penetrating power to .303 armour-piercing bullets. Seven hundred tons of this wire, sufficient for 80,000,000 rounds, were made. As the pressure of war increased it became necessary to speed up methods of fabricating steel structures by welding the parts wherever possible instead of riveting them. This called for a greater output of the wire electrodes used in the welding industry; wire made for this purpose amounted to as much as 30 tons a week.

Nearly all forms of wire mentioned so far were made on the same machines and by essentially the same methods as were used before the war. One task, however, which presented many new problems to Rylands and several associated industries was the manufacture of field telephone cable. When substantial orders for cable which, on the outbreak of war, had been placed overseas, failed to materialise, Australia was obliged to make her own telephone cable. There being no single organisation capable of doing the job, a conference of defence authorities and representatives of interested firms was held in Melbourne in October 1940. It was decided to proceed immediately with the design and construction of the necessary plant and equipment for mass production. The project was to be shared by the following firms, whose roles were:

B.H.P. Newcastle Steelworks—to produce rods of the appropriate steel.
Rylands Bros Ltd—to draw these rods into about 1,500,000 miles of wire, and tin it.
Metal Manufactures Pty Ltd, Port Kembla—to make and tin copper wire.
Australian Wire Rope Works Pty Ltd—to strand the steel and copper wires.
Olympic Tyre and Rubber Co Ltd, Footscray (Vic)—to cover, insulate, and test the cable.

The firms had to start virtually from scratch, designing and building their own equipment, yet within only a few months their coordinated efforts resulted in the output of more than 1,000 miles of cable a week.

The cable had to be capable of withstanding the wear and tear of the battlefront—it had to be tough, strong and flexible and resistant to deterioration by the weather, capable of withstanding wide ranges of temperature

(54 degrees Fahrenheit below and 158 degrees Fahrenheit above freezing point), and to possess the necessary electrical characteristics. The success of the whole scheme depended in large measure on the continued supply of extremely hard and accurate dies for the drawing process. Success was assured in January 1942 when B.H.P. succeeded for the first time in Australia in making cemented tungsten carbide, supplies of which could no longer be obtained from overseas. The stranding of seven tinned-steel wires and one copper wire, probably the most complex operation in the whole of the work, was followed by the final operation of providing a coating of rubber and cotton and paraffin wax.

A total of 233,000 miles of completed cable (enough to reach from the earth to the moon) was made, at prices well below those in Great Britain and the United States. The whole project was one of many instances of the pooling of resources and productive skills which characterised Australian industry during the war years.

Another of the more specialised tasks undertaken by Rylands was the making of control cables for aircraft—the Beaufort bomber, Beaufighter and others. This cable had to be light, flexible, but yet tough enough to withstand the terrific loads imposed on an aircraft's control surfaces during sharp manoeuvres in combat. Rylands provided a special fine wire of very high tensile strength—from 130 to 170 tons per square inch according to size, which ranged from 0.007 to 0.021 inches in diameter—for stranding into seven-strand cables. Australian Wire Rope Works Pty Ltd, which did the stranding, supplied some 3,220 miles of this cable.

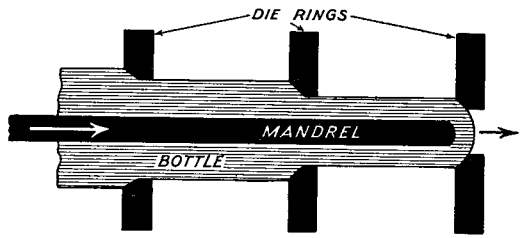
Another important job undertaken was the making of the Sommerfeld landing mat, a heavy netting designed to permit the rapid construction of air strips in the jungle and in advanced posts.

Tubes. There are two important methods of making steel tubes. One by a welding process (continuous weld) in which a length of hot steel strip is passed through rolls and formed and welded into tubular section with the edges abutting so that they weld together. This method, adopted in Australia by Stewarts and Lloyds at Newcastle in 1934, served to provide pipes up to three inches and a half in outside diameter for gas, water, steam and other services. Continuous-welded tubes found many structural applications in war: in pipelines for carrying water across the North African and Australian deserts; in supporting camouflage nets; for stretchers and bunk frames; in jungle carts for carrying men and stores; in portable structures used by the United States Army in the Pacific Islands as workshops and storage huts; and in the fabrication of bridges, pontoons and army huts.

The engineering applications of welded tubing were limited by the inherent weakness of the seam formed in the course of its manufacture; for many purposes, particularly where high pressures and temperatures were concerned, seamless tubing was essential. It was therefore most fortunate that in 1939, just before war broke out, Stewarts and Lloyds installed a "push-bench mill" for making seamless tubes, as this plant was

subsequently adapted to produce many wartime requirements. At the time of its installation the mill was one of the most up-to-date of its kind.

Seamless tubing was made at Newcastle in two steps. In the first, known as "piercing", a heated billet of square section was converted to a thick-walled, short, hollow cylinder by hydraulic piercing; in the second, known as "elongating", the thickness of the cylinder wall was reduced, and the bloom length greatly increased, by pushing it through a series of dies of gradually decreasing bore as is shown in the accompanying diagram.[5] Instead of solid ring dies, the Newcastle bench employed cages using idle rolls. The pushing was done by means of a rack and pinion, driven by a 1,050 h.p. electric motor. The whole process was highly mechanised and capable of high outputs.



One of the earliest adaptations of the seamless tubing plant was to the manufacture of 6-inch howitzer shells, which after some experimenting were produced with bores so accurately forged to size that they required no internal machining. The experience gained in making relatively short, thick-walled, cylindrical forgings on the seamless tube plant was of great value when Stewarts and Lloyds began to operate their special shell-forging plant, which had been built to operate on the same principle as the push bench. They became one of the important shell-producing centres in the Commonwealth: their final tally included 3,000,000 25-pounder shells, 750,000 4.5-inch howitzer and 3.7-inch anti-aircraft shells, and 100,000 6-inch howitzer shells. In the special shell plant Stewarts and Lloyds achieved rates of output quite as high as those of any other process. However it should not be concluded that the push bench or its modification was the only machinery used in forging shell bodies. The B.H.P. and Commonwealth Steel used the Baldwin Omes forging press, a unit imported from the United States.

The usefulness of the technique of making seamless tubes was not limited to ammunition. Its applications to the manufacture of cylinder barrels for aircraft engines were vital to the aircraft industry. Barrels were at first manufactured by Commonwealth Steel by the standard forging method, using steel from their electric furnaces. Orders for barrels became so great that they were quite beyond this company's capacity. It was therefore decided to make the steel in the open-hearth furnaces in the Newcastle Steelworks and to develop a method for mass-producing the barrels. In solving this latter problem as they did, by adapting the push bench mill, Stewarts and Lloyds overcame what had become a serious bottleneck in the manufacture and maintenance of aircraft engines.

[5] J. Porteous and P. L. Cotton, "The Manufacture of Hot, Cold Seamless and Welded Steel Tubing", *Proceedings of the Aisian Institute of Mining and Metallurgy*, No. 162 (1951), p. 217.

The production, storage and transport of compressed gases—such as oxygen, hydrogen, carbon dioxide, nitrogen and acetylene—was essential to many industries and to the Services, and necessitated the use of thousands of cylinders capable of withstanding high pressures. When gas cylinders became unprocurable from overseas, they were made in large quantities by Stewarts and Lloyds and by British Tube Mills (Adelaide). Thick-walled tubing, capable of withstanding still higher pressures, was made on the push bench for the chemical industry, particularly for the production of synthetic ammonia and methanol. Much of this tubing was cold-drawn to finished size by British Tube Mills.

The great expansion of the shipbuilding industry created a considerable demand for steel tubes; they were used for such items as stanchions, masts, cargo-handling derricks, and for ships' pipework. Pipes and tubes to Admiralty requirements were used in the construction of destroyers and corvettes. Water tube boilers for marine use, containing many miles of seamless tubing, also made heavy demands on the seamless mill.

The uses of seamless tubes were legion: either hot-finished, as they were at Stewarts and Lloyds, or cold-drawn, as they were at British Tube Mills,[6] they formed essential and integral parts of aircraft, tanks, Bren gun carriers, and every type of army transport vehicle; casings and mountings for machine-guns, trench mortars, mortar bombs, depth charges and mines; recoil cylinders for naval guns, and tubular forgings for torpedo propeller shafts. Had it not been for the development of the technique of making seamless tubes at Newcastle, most of these articles would have had to be made by the lengthy and tedious process of boring from a solid bar. Altogether over 500,000 tons of continuous weld seamless tubing were produced.

Except for armour plate, referred to earlier in this chapter, the rolling of steel sheets in the works of Lysaght's Pty Ltd continued with very little change in the peacetime technique. There was hardly a phase of war industry where steel sheets were not concerned. Lysaght's rolled about 400,000 tons of uncoated and 380,000 tons of galvanised steel sheets at their Newcastle and Port Kembla plants respectively, about 40,000 tons of which—sufficient for 137,000 Anderson air-raid shelters—was sent to the United Kingdom in the early part of the war. Chrome molybdenum steel sheets were rolled for the aircraft industry. Late in 1939 it became evident that the supply of hitherto imported silicon steel sheets for transformers, electric motors and generators would become restricted and eventually cease. These sheets were extremely difficult to manufacture successfully and production had been restricted previously to a few of the world's leading sheet and steel manufacturers. With the aid of information provided by the English works of John Lysaght Ltd, manufacture of motor grades was begun in 1940 and transformer grades in 1941.

Another form of steel sheet, though it is not usually described as such—cold-rolled strip made by the Newcastle steelworks—played an important

[6] British Tube Mills (S. Aust) used as their raw materials the hot-rolled tubes from Stewarts and Lloyds.

part in the manufacture of many different kinds of munitions. Approximately 30,000 tons of cold-rolled strip up to 12 inches in width and ranging in thickness from 0.187 to 0.010 inch, were used for such widely different articles as military buttons, toe and heel plates for military boots, rifle and machine-gun magazines and tail fins for aerial bombs.

All these articles of steel, and hosts of others besides, were made possible by the knowledge and resourcefulness of engineers and metallurgists and by the skill and patience of thousands of men and women working against time and circumstances to produce the material which, essential in peace, was the country's life-blood in war. Together they achieved things which even the most optimistic would scarcely have dared to predict in 1939.

CHAPTER 5

RAW MATERIALS: NON-FERROUS METALS

THE task of winning metals from the earth's crust can be divided into a number of well-defined steps: first there is the discovery and estimation of the size of the ore bodies in which the metals occur; then comes the mining of the ore and its treatment whereby the minerals it contains are concentrated so that they are ready for the last stage—extraction of the metals. These stages had been fully developed in Australia for all of the "big five" metals except aluminium; in the metallurgy of zinc, lead and copper—especially in the concentration and separation of their minerals by methods of flotation—Australia had made valuable and well-recognised contributions.[1] For other scarcer, but vitally-important metals, all degrees of exploitation, from practically zero to full utilisation, could be found in 1939.

Notwithstanding the fact that mining ranked high among Australia's primary industries, there was before the war of 1939-45 no national geological survey. Practically nothing had been done to collate the findings of the State geological surveys, with the result that the Commonwealth's geological staff, consisting of only two officers (the Geological Adviser and the Palaeontologist), was completely inadequate for the task of determining the country's total resources of the various minerals of wartime interest. The war saw two general developments of fundamental importance in the minerals industry: rapid growth of a Commonwealth-wide survey of mineral resources, and the initiation by the Division of Industrial Chemistry (of the C.S.I.R.) of a program of research directed towards more efficient and extensive use of indigenous minerals.

Few countries, if any, are self-sufficient in all the minerals essential to industry. Even one so well endowed by nature as the United States is without worthwhile deposits of quite a number of minerals. Australia is no exception, lacking commercially useful sources of chromium, nickel, and mercury. Metals in this group, important to industry and defence, but used in relatively small amounts, were often referred to as strategic metals. Their procurement and stockpiling was the responsibility of the Department of Supply and Development. Counterbalancing these deficiencies in Australian mineral resources were several metals (lead and zinc) and minerals (wolfram, scheelite, rutile, zircon, tantalite and beryl) whose output was greater than the country's needs, thus enabling Australia to make a valuable contribution to the material resources of the Allied Nations.

The Department of Supply and Development was entrusted not only with the importation of strategic minerals but also with initiating or increasing the local production of minerals and metals. Before dealing with its

[1] An account of the foundation work done by G. D. Delprat and L. Bradford at Broken Hill is to be found in *Principles of Flotation* by K. L. Sutherland and I. W. Wark, Australasian Institute of Mining and Metallurgy (Inc.), (1955).

more notable efforts in the latter direction it will be necessary, if a balanced picture is to be given of the production of non-ferrous metals, to refer briefly to the well-established metal industries.

Zinc. The beginning of the electrolytic zinc industry at Risdon (Tasmania) was closely associated with the first world war. In the early years of the present century Australia was second only to the United States as a producer of zinc ore, practically all of which was sent in the form of concentrates to Germany and Belgium for the extraction of the metal. When, after the outbreak of war in 1914, zinc concentrates from Broken Hill began to accumulate owing to the diminution of exports, and at the same time Britain began to look for increased supplies of high-quality zinc for her munitions program, Lieutenant Gepp[2] (an outstanding mining engineer, then an officer in the engineers of the Australian Military Forces) was sent to the United States in 1915 to investigate the extraction of zinc from its ores. While there he made an intensive study of the Anaconda Company's plant at Great Falls, Montana, where zinc was being recovered by the electrolysis of aqueous zinc sulphate solution, and gained practical experience in the operation of this process that was later to be of great value in Tasmania. He was present at the first experimental testings in California on the suitability of Broken Hill zinc concentrates for electrolytic extraction. About the time of Gepp's return to Australia the Electrolytic Zinc Company of Australasia Ltd was formed, and on his advice took an option over an offer of cheap hydro-electric power made by the Tasmanian Government. The Great Lake Scheme, then under the management of Mr Butters,[3] had reached a stage where there was power to spare for the encouragement of new industries.[4] The offer was accepted and work on the construction of the Risdon plant began. Production of zinc in 1917 came too late to be of much value in the first world war.

From then on, except during the years of the economic depression, the industry prospered and expanded and by 1939 it was a highly efficient industry and the third largest of its kind, with an annual output of approximately 70,000 tons. This being nearly twice Australian requirements for zinc, the industry was able to make a very substantial contribution to the needs of the Allied nations. At the beginning of the war the Electrolytic Zinc Company of Australasia Ltd entered into a contract, renewed from year to year until 1945, to sell specified quantities of zinc to the British Ministry of Supply. The metal, which was supplied at a price (£22 per ton) substantially below the price ruling in markets overseas (£32 per ton), represented a monetary advantage to Britain. Zinc was also exported

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[2] Sir Herbert Gepp. Gen Manager, Electrolytic Zinc Co of Australasia, 1916-26; Chairman, Development and Migration Commn, 1926-30; Director, North Aust Aerial Geological and Geophysical Survey; Managing Director Aust Paper Manufacturers Ltd 1936-50. B. Adelaide, 27 Sep 1877. Died 14 Apr 1954. Gepp, in collaboration with de Bavay, supervised the construction at Broken Hill of the first large-scale flotation plant ever built.

[3] Sir John Butters, CMG, MBE, VD. Hon Consulting Military Engineer HQ Staff AMF 1927-43; Chairman Associated Newspapers Ltd, Sydney, since 1940. B. Alverstock, Eng, 23 Dec 1885.

[4] The Great Lake Hydro-Electric Scheme was begun by a private company and later taken over by the Tasmanian Government.

to the United States and to India. In order to make sure of meeting the greater demands likely to be made on it, the Electrolytic Zinc Company, at the request of the British Ministry of Supply, undertook to extend its plant. Consequently production rose to a maximum in 1944 of 80,635 tons, of which 40,000 went to Britain. The accompanying table shows how the output of refined zinc varied over the war years.

Year	Production of zinc (in tons)	Sold to Aust consumers (in tons)	Percentage of zinc consumed in Aust
1940	75,957	40,552	53.4
1941	76,698	46,082	59.3
1942	74,282	54,526	73.4
1943	75,756	32,958	43.5
1944	78,716	19,828	25.2
1945	83,773	26,639	31.8
1946	76,316	35,984	47.2
1947	69,421	47,442	68.4

Australian production of refined zinc and the proportion allocated for domestic use.
Source: *Extractive Metallurgy in Australia*: *Non-ferrous Metallurgy* (1953). Ed. F. A. Green, p. 251.

Zinc found its most important use in galvanising (coating steel to reduce corrosion); next in importance was its use for making brass, one of the most useful of all alloys and extensively used in war time for cartridges and shell cases. Zinc was also an important component of alloys suitable for die-casting either by gravity or under pressure. Such castings could be made so reproducibly accurate (to within one thousandth of an inch or better) that their use avoided a great deal of the machine finishing ordinarily necessary on articles cast by older methods. During the war the technique of die-casting was extended considerably to enable the mass production of many accurately-dimensioned, small items of military equipment at speeds that would otherwise have been impossible. This development could not have taken place had there not been available supplies of zinc of a degree of purity exceeding that of the purest zinc generally available for commercial purposes. Unless the zinc used in making alloys for die-casting was specially free from traces of lead, castings made from the alloys would fail mechanically.

In 1935 Mr Williams,[5] Superintendent of the company's Research Department, began directing experiments to test the usefulness of ordinary electrolytic zinc, which had an average purity of 99.983 per cent, for making die-casting alloys. It was found that, although it was suitable for alloys used in making such everyday items as door handles, ordinary electrolytic zinc did not measure up to the more stringent requirements of military equipment. Specifications called for a zinc of better than 99.99 per cent purity and containing less than 0.007 per cent of lead, the most deleterious of all impurities so far as die-casting was concerned. Attempts made at Risdon over several years failed to reduce the lead content of the zinc below 0.01 per cent. The best results were achieved by carrying

[5] R. T. D. Williams. Research Superintendent, Electrolytic Zinc Co of Australasia for 30 years. Of New Town, Tas; b. Williamstown, Vic, 28 Jan 1885.

out the electro-deposition with lead anodes alloyed with 1 per cent of silver. After the Munitions Department had failed to reach an agreement with the New Jersey Zinc Corporation to secure details of its method for preparing zinc of 99.99 per cent purity by distillation, the Electrolytic Zinc Company resumed work on the problem.

Mr Hannay,[6] of the Consolidated Mining and Smelting Company of Canada, suggested the simple expedient of carrying out the electro-deposition at a lower temperature than was customary (28 instead of 35 degrees centigrade), as a possible means of further reducing the contamination of zinc with lead.[7] This proved to be the solution to the problem. In a small unit built for the purpose, 10,000 tons of zinc of 99.99 per cent purity, containing less than 0.005 per cent of lead, were produced. Most of it was used in the manufacture of an alloy known by the trade name "EZDA", which contained approximately 96 per cent zinc, 4 per cent aluminium and 0.05 per cent magnesium.

Lead. Australia, being second on the list of lead-producing countries, was also able to make a substantial contribution to the Allied war resources of this metal. The 1939 output of lead concentrates, sustained and even increased in the early years of the war, fell off later owing to the diversion of manpower at Mount Isa, Queensland, from lead to copper mining. The lead industry, which like the zinc industry had been greatly stimulated by the first world war, was well established by 1939 at two main centres: at Port Pirie, South Australia, where concentrates from the Broken Hill mines were smelted in the works of Broken Hill Associated Smelters Pty Ltd (which had the distinction of producing more lead in a year than any other and of being the first continuous refinery in the world); and at Mount Isa, where the Mount Isa Company smelted its lead concentrates to produce a lead bullion but did not remove silver from the bullion to form pure lead. The trends of activity in the lead industry and the extent of its contribution to the resources of the Allied nations during the war may be seen from the accompanying table.

Year	Production of lead (in tons)	Australian consumption (in tons)	Percentage of refined lead consumed in Australia
1940	189,150	28,797	15.2
1941	213,476	43,872	20.5
1942	206,929	48,122	23.3
1943	180,629	40,583	22.5
1944	154,547	29,853	19.3
1945	155,852	30,198	19.4
1946	137,459	42,040	30.6
1947	158,548	33,242	21.0

Source: *Extractive Metallurgy in Australia*, p. 256.

[6] W. H. Hannay. Member of Research Board Consolidated Mining & Smelting Co of Canada. B. Belfast, Ireland, 16 Jan 1882.

[7] D. H. Johnstone, "Production of Electrolytic Zinc at the Works of the Electrolytic Zinc Co of A/sia Ltd, Risdon, Tasmania", from *Extractive Metallurgy in Australia: Non-ferrous Metallurgy* (1953), p. 96.

Magnesium. On account of its lightness, magnesium, usually alloyed with aluminium, figured prominently among the metal components of aircraft. The technology of magnesium, the lightest of all metals in use for constructional purposes, had been most highly developed in Germany, with the result that that country was the world's leading producer. Magnesium was in fact the only metal of which Germany had an exportable surplus. Its uses had been more thoroughly exploited there than in any other country, but other highly-industrialised nations were not far behind. Britain and the United States had set up plants in the late nineteen-thirties for the recovery of magnesium from sea water, but owing to the unprecedented demand for magnesium for aircraft construction and for other defence purposes, the output of these plants was insufficient to prevent a widespread shortage of the metal in the early part of the war. The seriousness of the situation was underlined about the middle of 1940 by Britain's intimation that she would no longer be able to supply Australia with magnesium.

Fortunately the B.H.P., foreseeing the country's need for this metal, had taken the initiative, and after preliminary negotiations with the British firm of Murex Ltd of Rainham, Essex, had sent two of its technical officers, Messrs Henderson[8] and Norgard,[9] to England to study the metallurgy of magnesium. They arrived on 27th July 1940. Almost exactly one year later the plant at Newcastle began to operate.

Basically the process used was the then novel one of thermal reduction carried out in gas-fired, heat-resistant, steel retorts: magnesium oxide, mixed with finely ground calcium carbide,[1] was heated *in vacuo* to a temperature of 1,150 degrees centigrade and the magnesium was distilled off. Remelting and alloying were carried out under a suitable flux, since at temperatures above its melting point magnesium readily takes fire. Finely powdered magnesium, which burns with an extremely brilliant white flame, was used in flares, star shells, ignition mixtures and photographic flash foils and filaments. Pure magnesium has relatively little strength and in this form its uses were limited to those just mentioned and to certain metallurgical practices; for instance, it was used as a deoxidiser in casting aluminium, brass and bronze. Light alloys of considerable strength and usefulness, especially in the aircraft industry, could be made with magnesium and small quantities of several other metals.

During the war the B.H.P. produced 2,582,000 pounds of magnesium, of which 2,019,375 pounds were used for making special alloys and the remainder for pyrotechnical preparations. The accompanying table shows

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[8] E. T. Henderson. Officer in charge of Magnesium Plant, BHP, Newcastle, from its inception; helped establish tungsten-carbide and ferro-alloy plants at BHP, Newcastle. Metallurgist; b. Glen Osmond, SA, 26 Mar 1877. Died 15 Jan 1950.

[9] F-Lt J. D. Norgard, BEMet. Metallurgist, B.H.P. Co Ltd; served RAAF 1942-45. Manager, BHP Steelworks, Newcastle, NSW, since 1952. Of Adelaide; b. Adelaide, 3 Feb 1914.

[1] Calcium carbide from Electrona, Tasmania, was used in the early stages, but later the B.H.P. made its own.

the composition of magnesium alloys belonging to the Elektron series produced by B.H.P. for making castings of aircraft parts.

Designation of alloy	Aluminium	Zinc	Manganese	Magnesium
	%	%	%	%
Y	6	3	0.3	90.7
X	7.8	0.4	0.3	91.5
W	9.5	0.4	0.3	89.8

Magnesium alloys containing over 6 per cent of aluminium could be greatly improved in mechanical and other physical properties by heat treatment, which involved maintaining the metal at predetermined temperatures for specified periods of time (23 hours at 420 degrees centigrade, followed by 9 hours at 200 degrees centigrade). Temperatures had to be maintained within quite narrow limits if batches of material were not to be spoiled. In checking the accuracy of commercial temperature-measuring instruments, the Physics Sections of the National Standards Laboratory and the Munitions Supply Laboratories gave indispensable help to the metal industry. The manufacture of these alloys exemplified a new general trend brought about by the demands of war. Manufacturers of munitions were required to adhere rigidly to specifications relating to the composition and heat treatment of alloys far more exacting than those to which they had formerly been accustomed.

Because of the great falling off in demand for magnesium after the war the industry was abandoned.

Copper and Bauxite Committee. As supplies of strategic minerals became short, hurried searches revealed wide gaps in the knowledge of Australia's mineral resources. There is little doubt that Australia was caught at a disadvantage compared with countries, such as the United States, Canada and India, which had national geological surveys and, as was the case with the first two, bureaux of mines. The situation was aggravated by the slump that occurred in many branches of the mining industry early in the war as a result of the drift of men away from the mines. Local production of minerals had fallen well below pre-war levels and it was clear that some decisive action was needed to prevent a major collapse in the industry. Copper and aluminium were the two metals that caused most concern.

It was for the purpose of advising the Government on the most suitable ways of stepping up local production of copper and of beginning an aluminium ingot industry that the Commonwealth Copper and Bauxite Committee was set up in May 1941 within the Department of Supply and Development, under the chairmanship of Sir Colin Fraser.[2] For many years

[2] Other members of the committee were: Dr H. G. Raggatt (C'wealth Geological Adviser, Deputy Chairman), A. J. Keast (Zinc Corp Ltd), J. M. Newman (independent mining engineer), M. J. Martin (Sulphates Pty Ltd), J. Horsburgh (Mt Morgan Co) and A. C. Smith (Dept of Supply and Development), who was Secretary to the Committee.
This committee was later increased in size and called the Minerals Committee. It ceased to function in 1942 when the Minerals Production Directorate in charge of Mr J. M. Newman was formed.

Fraser had exerted a powerful influence on the metals industry in Australia, and the standards of efficiency to which it had attained contributed in no small measure to the success of the munitions program. As Adviser to the Government on Non-ferrous Metals he had already given valuable service to the country.

Copper. From being a large producer and an exporter of copper, Australia was reduced in the decade before the war to a level where she was barely able to supply her own needs. When the munitions program called for greatly increased supplies of copper to make the brasses, bronzes and other copper alloys used in cartridges, shell cases and similar components, a serious shortage was threatened. Copper was smelted at four main centres in the Commonwealth: at Port Kembla by the Electrolytic Refining and Smelting Company of Australia; at Queenstown, Tasmania, by the Mount Lyell Mining and Railway Company Ltd; and at Mount Morgan Ltd and Mount Isa Mines Ltd in Queensland. The Mount Lyell Company, operating on an extremely low-grade copper ore (the lowest exploited on a large scale anywhere in the world), was unable in spite of the high efficiency of its metallurgical processes, to increase its output. Neither could the output of Mount Morgan be increased. Consequently it became imperative to look for other sources of copper. It was due mainly to the efforts of the Copper and Bauxite Committee that attention was drawn to the possibility that Mount Isa, previously a producer of zinc and lead, might be exploited for copper.

In normal times, when much proving and testing of ore bodies and metallurgical processes is done before large sums of money are committed, mining is generally regarded as a financially hazardous undertaking. Under war conditions the hazards are even greater, especially when attempts are made to bring back into production mines which have been closed down because they were unprofitable, or to open up new ventures in a great hurry. In war, when a metal was urgently needed for the manufacture of arms and the cost of producing it was a matter of secondary importance only, the Government often provided financial assistance to mining industries, as it did with Mount Isa. In this way Mount Isa came into production towards the end of 1943 with an annual output of about 6,000 tons of copper. A fortunate circumstance in which a large copper-ore body was found close to the main lead-zinc body made it possible for the two to be developed from the main set of workings. Copper from Mount Isa was obtained at the expense of a reduction in the output of zinc and lead, but as already mentioned these two metals were being produced in amounts far beyond Australia's requirements. Most of the copper smelted at the various centres was subsequently refined electrolytically at Port Kembla and Queenstown. The accompanying table, which sets out the quantities of metal so treated, also gives some idea of the output of copper over the war years. The table does not show

all the copper produced. There was, for example, a carry-over of 9,910 tons of Mount Isa blister copper not shown in the figures for 1944.

	Blister Copper Electrolytically Refined				
	1940	1941	1942	1943	1944
Port Kembla					
E.R. and S. Co.	3,205	3,593	3,147	6,656	5,258
Chillagoe	2,352	1,901	1,652	1,437	—
Mt Morgan	3,592	5,775	4,174	4,054	3,088
African	2,124	4,836	—	—	—
Mt Isa	—	—	—	1,897	6,691
Queenstown					
Mt Lyell	12,022	8,507	12,630	10,760	8,556
TOTAL	23,295	24,612	21,603	24,804	23,593

Much credit is due to the mining engineers and metallurgists who, under the leadership of Mr Kruttschnitt,[6] brought Mount Isa into production of copper in so short a time. Mines such as the Lake George mine at Captain's Flat, New South Wales, were brought back into production, and the total annual output of copper was raised to about 30,000 tons—almost double that of the years immediately preceding the war. Although still below wartime requirements, which at the peak rose to 75,000 tons a year, this represented a substantial contribution, and together with 131,000 tons of copper that had been imported from Africa by the Commonwealth Government and stock-piled, coupled with the savings brought about by severe restrictions in the use of copper for civilian purposes, tided the country over the war years, with some to spare.

One lesson that emerged from the attempts to increase mineral supplies during the war was that it was seldom, if ever, practicable to open up entirely new large-scale developments. In war it is almost always a case of making the most of the existing mines and at best extending their working, as was done at Mount Isa.

Aluminium. The second task of the Copper and Bauxite Committee was to investigate the local supply of bauxite, the raw material required for the extraction of aluminium. In spite of the fact that there had been announcements on the part of big metallurgical companies, dating as far back as the first world war, that they were about to begin the extraction of aluminium, no detailed survey had ever been made of the sources of bauxite in Australia. These companies appear to have been deterred from launching the industry because of fear of competition from powerful world aluminium combines. But as no country could develop an aircraft industry without an assured supply of aluminium, government intervention seemed to be the only way of starting an aluminium industry. Surveys initiated by the Copper and Bauxite Committee revealed the existence of sufficient medium-grade bauxite in Queensland, New South Wales, Victoria and

[6] J. Kruttschnitt, PhB. Gen Mgr Mount Isa Mine 1930-37; Chairman, Bd of Directors, Mount Isa Mines Ltd, 1930-52. B. New Orleans, U.S.A., 7 May 1885.

Tasmania to support an annual production of 6,000 tons of the metal a year; the highest grade deposits were found in Victoria, and proved to be considerably larger than was at first estimated.[7] Commercially useful bauxite was unknown in Tasmania until late in 1941 when an ore-body estimated to contain 500,000 tons of 41.2 per cent alumina was discovered in the Ouse Valley. Later exploration on Wessel Island, north-east of Arnhem Land, revealed the presence of 10,000,000 tons of better-grade bauxite than any previously discovered on the mainland.

Two metallurgists, Messrs Keast[8] and Hey,[1] were sent by the Government to examine the aluminium industries of Great Britain, Canada and the United States. They found, as they had expected, that throughout these countries the only processes used for producing aluminium were the Bayer process for purifying the bauxite and the Hall electrolytic process for the extraction of the metal. Although during the early part of the war large sums of money were spent by the United States War Production Board and Bureau of Mines in efforts to increase the production of aluminium, no new process reached the commercial stage. Alternative methods of purifying bauxite which did not require the large quantities of caustic soda used in the Bayer process and then in short supply, were worked out by White Metals Pty Ltd and Sulphates Pty Ltd, Victoria. Despite the fact that they seemed quite promising, they were not followed up, for the reason that caustic soda once more became plentiful.

An essential requirement for the economic extraction of aluminium from its ores was an ample supply of cheap hydro-electric power. Experience had shown that there was a minimum size for a metal extraction industry below which it became uneconomic. The number of electrolytic cells needed for most efficient operation was smaller for aluminium than for most other metals. It so happened that this minimum coincided roughly with the size of the plant contemplated for Australia: one capable of an annual output of 6,000 tons of aluminium. The quantity imported before the war was much less than this, amounting to a little over 1,300 tons a year, but it rose considerably after 1939, reaching an average of about 9,000 tons in the war years. However these plans were baulked by the refusal of the United States to supply under Lend-Lease the necessary plant and technical information.

By 1944 all danger of an aluminium famine had passed; importation of 10,000 tons from Canada during that year removed the immediate need to produce aluminium locally. However the basic importance of aluminium to Australian industry was not forgotten; in April 1944 an agreement was reached between the Commonwealth and Tasmanian Governments under the Aluminium Industry Act to establish the industry in Tasmania and in May of the following year the Australian Aluminium

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[7] Development of this field was carried out by Sulphates Pty Ltd, Vic.

[8] A. J. Keast, CBE, MM. (Served 1st AIF and RAF.) General Manager, Broken Hill Assoc Smelters, 1947-50; General Manager, Aust Aluminium Production Commission, 1951-55. B. Kiata, Vic, 21 Jun 1892.

[1] H. Hey. Chief Metallurgist, Electrolytic Zinc Co, 1927-43, Technical Superintendent 1943-44, Chairman and Mg Dir since 1952. B. Horbury, Eng, 20 Jun 1892.

Production Commission was constituted. At its inaugural meeting in Hobart on 12th May 1945 the scope of its activities was outlined by Mr Makin, the Minister for Munitions. The guiding motives were now dictated by a desire to establish an economically sound industry instead of one improvised under war conditions, and a less hurried approach was made to the whole question. The sequel will be described in the final chapter of this volume.

Non-ferrous metal fabricating industries. The growth in Australia of factories where copper, zinc, lead and other non-ferrous metals and their alloys were wrought to basic shapes such as plate, sheet, strip, rod, sections, wire and tubes,[2] for subsequent use by the numerous units of the finishing industry, was a feature of the inter-war period.

With capital provided to a large extent by Australian mining companies, and technical assistance and machinery provided by established oversea firms, especially by British wire and cable interests, a large manufacturing centre was built up by Metal Manufactures Ltd at Port Kembla to produce an almost complete range of rolled, extruded and drawn shapes in copper. All the high-conductivity copper wire, as well as much other non-ferrous metal wire (aluminium and steel-cored aluminium) used in the electrical industry was made by this company. Austral Bronze Company Ltd of Alexandria, a subsidiary of Metal Manufactures, produced most of the copper and copper-alloy plate, sheet and strip, extruded rods, bars and sections and alloy wire used in Australia.

To be near the main government munitions factories, both companies established branch factories at Maribyrnong, where a similar but more limited range of products was made. About the same time the Austral Bronze Company built an annexe at Derwent Park, Tasmania, for rolling copper and copper alloys. Early in the war great extensions in the facilities for metal manufacturing were made by the government munitions factories themselves; here, especially in the ammunition factories at Footscray and at Hendon, South Australia, were made practically all the requirements of copper, lead and tin alloy sheet and strip for use in the manufacture of cases and detonator caps for small-arms ammunition, cases for gun ammunition and for many other purposes. All these were key industries, for in the manufacture of munitions copper and its alloys were exceeded in importance only by iron and steel.

By far the greater part of the fabrication of zinc in this country was in the hands of two companies: the Century Storage Battery Company Ltd and Metals and Ores Pty Ltd, both of Alexandria, New South Wales. The former, operating since 1935, produced a considerable proportion of the sheet zinc used in lithographic and photo-engraving work. In a factory designed with technical assistance from the United States but operated by an Australian staff, Metals and Ores Pty Ltd, a subsidiary of Eveready (Australia) Pty Ltd, began a new venture in 1942: the rolling of sheet zinc for the rapidly expanding dry battery industry.

[2] The operations involved are referred to collectively as metal manufacturing.

Perhaps the most noteworthy development of the metal manufacturing industry in Australia during the second world war was the fabrication of aluminium, a development closely linked with the decision to manufacture aircraft. In the late thirties a group consisting of the British Aluminium Company Ltd, the Aluminium Company of Canada Ltd, Electrolytic Zinc Company of Australasia Ltd, and Metal Manufactures Ltd, formed the Australian Aluminium Company Pty Ltd. Rolling mills and a 3,000-ton horizontal hydraulic press for the extrusion of rods, bars and sections ordered by the company from Britain in 1939 were never delivered in Australia. Soon after the plant was completed it was transferred to the British Government, whose needs for aircraft at that time were urgent. A duplicate set of equipment ordered in the United States was ready to be delivered to Australia when Lord Beaverbrook intervened to have it transferred to Britain. Only after the intercession of the Australian Prime Minister, Mr Menzies, was the transfer cancelled and the equipment finally shipped to Australia; it was installed in the newly-completed works of the Australian Aluminium Company Ltd at Granville, New South Wales.

Provision was also made for casting and forging aluminium and its alloys; a special annexe operated on behalf of the Commonwealth Government was equipped with a drop hammer of 35,000 pounds' capacity for making large aluminium alloy forgings—propeller blades, crank cases, and tail wheel forks for aircraft.

The second largest fabricator of aluminium was G. E. Crane and Sons, whose factory at Concord, New South Wales, equipped with modern rolling mills and a first-class engineering workshop, was in point of fact the first to produce light alloy (aluminium base) aircraft sheet.[3] This company had fortunately just completed the installation of new and improved mills and ancillary plant intended for copper and brass sheet when the government aircraft program first began. Conversion to the processing of aluminium and its alloys was soon accomplished and the company took its place as an important supplier of material to aircraft factories. All the ingot aluminium used in these factories came from the Canadian Aluminium Company, which not only supplied large quantities of the metal (20,000 tons) but did so according to the promised schedules.

In the early thirties Professor Laby[4,5] had directed a team of geophysicists in the application, under the auspices of the Imperial Geophysical Experimental Survey, of the then-known methods of geophysical prospecting, to the testing of known ore bodies, and in the search for new ones. Expansion of this work was hampered to some extent by the fact that in no Australian university was there a department of geophysics (or, for that matter, of geochemistry), but in spite of this a small group of geophysicists was built up during 1934-41 by the Aerial, Geological and Geophysical Survey of

[3] A third factory for fabricating aluminium was built at Wangaratta, Vic, but it was completed too late to warrant its being put into operation.

[4] With the cooperation of Messrs Broughton and Edge.

[5] T. H. Laby, FRS, MA, ScD. Professor of Natural Philosophy, Univ of Melbourne, 1915-44; first President, Institute of Physics of Aust. B. Creswick, Vic, 3 May 1880. Died 21 Jun 1946.

Northern Australia. Its geophysicists were drawn largely from Australians who took part in the Imperial Geophysical Experimental Survey.

The small geological organisation in the Department of the Interior, known as the Geological Branch, was transferred to the Department of Supply and Development at the end of 1941. Early in 1942, at the request of this department, a committee of geologists appointed by the Australian National Research Council, with Professor Cotton[6] as Chairman, prepared a comprehensive report covering existing knowledge of the mineral resources of the Commonwealth.

As a result of the presentation of this report, the Geological Branch was increased in size by the addition of the geophysicists from the Aerial, Geological and Geophysical Survey, and the appointment of additional geologists, and renamed the Commonwealth Mineral Resources Survey. Dr Raggatt,[7] then Commonwealth Geological Adviser, was made Director of the Survey with Mr Nye[8] as Assistant Director. Thus began the first comprehensive and systematic attempt to coordinate the knowledge of the Commonwealth's mineral resources. It was restricted at first to minerals of importance to the war effort, but was later extended to include all minerals and to result in the formation of the first national geological survey.[9]

The State Mines Departments had a very good knowledge of the mineral resources within their own borders, but something more than that was required for planning a mineral industry and for meeting the calls made upon Australia by the Allied Nations. The great need was for coordinating information concerning the resources, production and consumption of minerals and for surveys on an Australia-wide basis.

Japan's entry into the war in December 1941, resulting as it did in the loss of important world sources of tungsten and tin in South-East Asia, greatly intensified interest in Australian resources of these metals. After the scope of the surveys of mineral resources had been widened, a corresponding expansion in the organisation for producing minerals took place, in March 1942, with the formation within the Department of Supply and Development of a Directorate of Minerals Production under Mr Newman,[10] a leading mining engineer. The National Security (Minerals) Regulations gazetted on 6th March 1942 gave Newman wide powers of operating, controlling and directing the production and supply of minerals throughout the Commonwealth, and authorised him to take any measures he thought necessary or expedient to those ends. From the outset it was planned that the Commonwealth Mineral Resources Survey should co-

[6] L. A. Cotton, MA, DSc. Prof of Geology and Physical Geography, Univ of Sydney, 1925-48; Prof Emeritus since 1948. B. Nymagee, NSW, 11 Nov 1883.

[7] H. G. Raggatt, CBE; DSc. C'wealth Geological Adviser 1940-51; Dir, Bureau of Mineral Resources, 1942-51; Sec, Dept of National Development, since 1951. B. North Sydney, 25 Jan 1900.

[8] P. B. Nye, OBE; MSc. (Served 1st AIF.) Govt Geologist, Tas, 1923-34; Asst Dir, C'wealth Bureau of Min Resources, 1942-51, Dir since 1951. B. Collingwood, Vic, 21 Mar 1893.

[9] An account of the formation of the Bureau of Mineral Resources is given in the last chapter.

[10] J. M. Newman, CBE; BE. C'wealth Controller of Minerals Prodn 1942; Director of mining companies in Aust, New Zealand and Malaya. B. Caboolture, Qld, 20 Jun 1880.

operate closely with the Controller of Minerals Production. The two organisations, in fact, used common files although they functioned separately.

Newman made full use of the facilities and experience of private mining companies, which cooperated in the development of undertakings and also provided much expert technical advice. This was particularly true of the Zinc Corporation, North Broken Hill, Broken Hill South, Mount Isa Mines and Lake George Mines. With the aim of enlisting the aid of all government mining administrations, Newman appointed as his delegates heads of Departments of Mines in all States—an arrangement which, operating smoothly, enabled the fullest use to be made of the resources of State departments. In carrying out his work as controller, Newman was constantly hampered by the fact that it was impossible at any time during the war to determine with any degree of accuracy Australian requirements of metals and minerals. There was of course no novelty in this; the same could be said about the supply of almost any material in almost any country at war. He was, however, aware of the main metals and minerals whose local output should be increased—copper, aluminium, tungsten, tin, beryllium, mica, molybdenum, tantalum, antimony and arsenic, quartz crystals, and asbestos—and control of production and distribution was concentrated mainly on these.

Tungsten. When the Japanese overran China, Thailand, Burma and Malaya they cut the Allied nations off from the source of roughly 60 per cent of the world's tungsten. Without tungsten, which was indispensable for making special steels, radio valves, electric lamps and tungsten carbide, the manufacture of munitions would have been seriously impeded. Australian production of tungsten concentrates, in the neighbourhood of 1,000 tons a year before the war, had dropped to 800 tons by the end of 1941, owing partly to the drift of labour from the mines. In answer to an urgent appeal from the British Government early in 1942, the Controller of Minerals took steps designed to stimulate the production of tungsten concentrates (wolfram and scheelite), in some instances by establishing government enterprises and in others by providing financial assistance to companies and individuals; and in general by ensuring the highest priorities for manpower, plant and equipment. The major enterprise operated by the Government was a failure. Some 600 Chinese workers evacuated from Nauru and Ocean Islands where they had been working for the British Phosphate Commissioners, were sent to the Hatches Creek and Wauchope tungsten mines in the Northern Territory. Unfortunately these workers proved uncooperative and ill-fitted for the work. At the end of 1943 they were taken over by the United States Army and arrangements were made to replace them by Italian workers. The replacement was never made, because by that time the urgent need for tungsten had passed.

The prospects of producing large quantities of tungsten concentrates from the different private ventures were not good because they were as

a rule small and widely dispersed. Much effort was spent on exploiting them, with disproportionately small returns. The outlook changed early in 1943 when, as a result of surveys made by Mineral Resources Surveys in the previous year, the true extent of the scheelite deposit on King Island (in Bass Strait) was ascertained. The deposit appeared to be the largest of its kind anywhere in the world. Its existence had been known for many years and it had been worked from 1916 to 1920.[8] In 1938 the mine was re-opened, but its output rapidly declined—from 275 tons in 1940 to 32 tons in 1944—owing mainly to shortage of labour and more particularly to the reorganisation of the plant which took place towards the end of that period. By then the Allies had all the tungsten they needed, but notwithstanding this, reorganisation of the mine and treatment plant was continued.

In spite of the vicissitudes of the different ventures, and in the face of difficulties arising from fierce competition for machinery and manpower, Australia was able to fulfil her own needs for tungsten as well as to supply 2,000 tons of concentrates (valued at £1,000,000) to the British Government at a time when they were urgently needed. The B.H.P. extracted approximately 500,000 pounds of the powdered metal, besides consuming a good deal of tungsten concentrates in the manufacture of ferro-tungsten. Much of the powdered tungsten was used for making tungsten-carbide tool tips; some was used for making wire. The Metallurgy School of the University of Melbourne designed and constructed a plant for the fabrication of tungsten rod and wire at the rate of about half a ton a year. It was in operation between 1943 and 1944 but thereafter was completely abandoned, presumably because tungsten wire could be imported more cheaply. Having developed the specialised techniques of powder metallurgy required to fabricate tungsten, it might seem a mistake that the whole thing was abandoned, since in the event of another war it would have to be built up again. As with most apparently lost opportunities of this kind, the reasons were mainly economic: the needs of the whole of the Australian electrical industry (lighting and radio) were insufficient to make it worth while to continue manufacturing tungsten wire locally.

Tin. From being the world's leading producer of tin (between 1873 and 1882), contributing 25 per cent of the world's supplies, Australia had by 1939 fallen to ninth on the list with a contribution only 2 per cent of the world total. Even this reduced output was more than ample for the country's peacetime needs. Tin was one of the essential metals, both for munitions and peacetime industry, for which it was often impossible to find an adequate substitute. About 35 to 40 per cent of the world's tin was used in the manufacture of tinplate, without which the food-canning industry would be at a serious disadvantage. Owing largely to the opposition of oversea interests, Australia at this period had no tinplate industry and was thus entirely dependent on outside supplies.

[8] It was discovered by Mr T. Farrell, and in 1916 was reported on by Mr L. Waterhouse, at that time Assistant Govt Geologist in the Tasmanian Mines Dept. The later assessment was made principally by P. B. Nye and M. A. E. Mawby.

Tin was an essential component of many alloys—bronzes, gun metals and solders—and it was mainly for these purposes that tin was used in the munitions program. Greatly increased consumption was expected during the war (it actually rose from about 2,100 tons in 1939 to 3,000 tons in 1942). After the loss of the Malayan tin mines, the principal source of world supplies, the Australian Government was informed by the Raw Materials Board in Washington that it would have to rely on its own tin resources to supply its needs and that it should also make itself responsible for satisfying the needs of New Zealand. Before the war a substantial proportion of locally-produced tin came from small producers, and in the early years of the war many of these men left the industry, with the result that the increased Australian needs could not be met. The Minerals Production Directorate promptly took over the Mount Bischoff tin mine in north-west Tasmania and operated it for several years. This mine, once among the great tin producers of the world, had gradually fallen off in its output until, just before the war, it was producing no more than 126 tons a year and was in danger of being closed down. Its revival did not long outlast the war since reserves were practically exhausted and the mine was no longer capable of economic operation. The directorate also took over the alluvial tin deposits of the Dorset flats in north-eastern Tasmania and installed a dredge, a project which was still being operated by the Commonwealth Government ten years after the war. By giving extensive financial and technical help to many small producers and by rigid control over the uses of tin for purposes other than making munitions, the Government ensured that wartime needs of tin were met.

Cobalt. No attempt had been made to extract metallic cobalt in Australia before the war. The problem of satisfactorily disposing of cobalt nitroso-β-naphthalate, the form in which the metal was removed in the course of purifying zinc sulphate solutions before electrolysis, had occupied the research department of the Electrolytic Zinc Company for many years. It was the demand which sprang up during the war for metallic cobalt to make cemented tungsten carbide tool tips and special magnetic alloys (such as the alnico alloys), that first provided a useful outlet for the small amounts of cobalt recovered at Risdon, Tasmania.

About this time New Zealand and Australian scientists working on problems of animal nutrition discovered that sheep grazing on pastures deficient in cobalt became subject to serious malnutrition, from which they often died; further, that the disease could be cured by the simple expedient of adding cobalt salts to the deficient soils. Cobalt in the form of cobalt sulphate, also made at Risdon, was supplied to agriculturalists for incorporation in fertilisers, so providing another outlet for this useful by-product.

Antimony and arsenic. When supplies from Wiluna, Western Australia, the largest producer of antimony in Australia, began to show signs of falling off, the Directorate of Minerals Production arranged to bring into operation, as government enterprises, several areas in Victoria (including

Coimadai and Costerfield), in order to guarantee adequate supplies of this metal, which found extensive use in the munitions industry for hardening the lead used in bullets and storage batteries. O. T. Lempriere and Co Pty Ltd, Sydney, furnished the whole of the Australian requirements of antimony, antimony oxide, and sodium antimonate. Large amounts of the oxide were used during the war in making up flame-proofing mixtures for treating canvas. Australia was also able to supply her own needs of the closely related element arsenic and to send 3,000 tons of arsenic to the British Government in response to an urgent order after the fall of France.

It has been said that the extent to which unprocessed minerals are exported from a country may be taken as a rough index of its lack of industrial development.[9] In applying this criterion it must be remembered that in 1939 there were some metals that were extracted from their ores only in the most highly industrialised countries. Australia had a number of ore deposits in this category, such as those containing the metals tantalum, beryllium and titanium.

Tantalite. Western Australia and the Northern Territory were notable for their deposits of rare metals; the former possessed at Wodgina a deposit of tantalite, source of the metal tantalum, which for its size and the high ratio of tantalum to columbium in its ores was unique.[1] The first tantalite mined anywhere on a commercial scale came from this field in 1905, and up to 1939 Australia enjoyed a world monopoly in the production of high-grade tantalite. Until that time nothing had been done to process tantalite locally. In 1942 Professor Greenwood[2] and Mr Myers[3] of the Department of Metallurgy in the University of Melbourne, following methods worked out in Europe and the United States and working on a laboratory scale only, separated Australian tantalite ores into the complex fluorides of tantalum and columbium.[4] They made the carbides of each of these metals and later isolated the metals themselves. Before any commercial use could be made of this laboratory work,[5] the Commonwealth received an urgent request from the United States Government for as much tantalite as could be supplied. A contract was made with the Metal Reserve Corporation of the United States by which the Commonwealth would supply 165 tons of concentrates assaying 60 per cent tantalum oxide. Small as this amount may sound, it was a tall order, for

[9] R. Grenfell Thomas, "Chemical Processing in the Australian Mineral Industry", *Journal of the Society of Chemical Industry of Victoria,* Vol. 43 (1943), p. 483.

[1] These two metals always occur together. At the time there was greater interest in the use of tantalum.

[2] J. N. Greenwood, DSc. Professor of Metallurgy, Univ of Melbourne, 1924-45, Research Professor of Metallurgy since 1946. B. St Helens, Eng, 12 Dec 1894.

[3] R. H. Myers, MSc, PhD. Commonwealth Research Fellow, Univ of Melbourne, 1941-47; Research Officer Atomic Energy Research Estab, Harwell, Eng, 1948-52; Prof of Metallurgy, NSW Univ of Technology, since 1952. Of Melbourne; b. Melbourne, 21 Feb 1921.

[4] R. H. Myers and J. N. Greenwood, "The Processing of Tantalite Ore and the Preparation of the Carbides of Tantalum and Columbium", *Proceedings of the Aust Institute of Mining and Metallurgy,* New Series, No. 129 (1943), p. 41.

[5] The experimental work on the carbides found application in the manufacture of sintered carbide cutting tools.

tantalum is an exceedingly rare metal. In an attempt to meet it quickly the Controller of Minerals bought up parcels of concentrates from scattered small producers, and at the same time took over the Wodgina tantalite mines.

At one stage of the war the need for tantalum was so acute that 18 tons of tantalite concentrates were actually flown from Australia to the United States. It was there that the entire requirements of the Allied nations for refined tantalum metal were produced. Although more equipment was installed at Wodgina in order to treat an increased output of ore, the results proved disappointing. After about 3,500 tons of crude ore had been mined, the deposit gave out; the total quantity of tantalum concentrates exported to the United States did not amount to more than 24 tons assaying 65 per cent tantalum oxide. This, while far short of the contracted amount, did make up a substantial proportion of the requirements and was therefore a most useful contribution. The project, which involved the Directorate of Minerals Production in a loss of more than £100,000, was written off as a direct contribution to the Allied war effort.

Most of the numerous uses to which tantalum metal was put depended on its extraordinary resistance to corrosion. It is outstanding in its suitability for implantation in the human body, and much of the metal was used in the manufacture of thousands of surgical plates, wires, tubes and ligatures. Another important wartime use for tantalum was in the form of alloys with tungsten and nickel in the manufacture of radio and radar valves. Compounds of tantalum found two important applications. Firstly, potassium tantalum fluoride was widely used as a catalyst in the making of butadiene, starting material for one of the most important of the synthetic rubbers (Buna S). Secondly, small amounts of tantalum carbide were mixed with tungsten carbide in making cemented tips for machine tools; during 1943 and 1944 Hard Metals Pty Ltd of Sydney, a subsidiary of Australian General Electric Pty Ltd, consumed 1,389 pounds of tantalite in the manufacture of tool tips. This was the only instance of the commercial use of processed tantalum concentrates in Australia during the war years. For some years after the war the output of tantalite in Australia slowly declined, reaching 1 or 2 tons a year in the period 1947-48. Deposits of the ore in sight had been practically exhausted, and ruling prices offered little incentive to further exploitation.

Beryl. When, towards the end of 1942, the United States advised the Commonwealth Government that it urgently needed large supplies of beryl (the only mineral so far used commercially for the extraction of beryllium), a hurried search had to be made for possible sources of supply. The delay that occurred in locating sources was inevitable in the absence of a national survey of mineral resources. It so happened that the demand could have been met from one mine in Western Australia, but this information was not revealed until every State in the Commonwealth had been written to and until the replies had been examined and

compared.[6] In any well-organised survey of mineral resources it would have been available instantly.

Beryllium is a very light, extremely hard, and somewhat brittle metal with a lustre resembling that of a freshly-cut surface of lead. It is difficult to machine and is highly resistant to corrosion. At this time the metal itself was not widely used but its alloys were highly prized, for reasons which make wartime demands for it clear. Beryllium-copper, for example, possessed to an unusual degree resistance to fatigue combined with great strength, hardness and resistance to corrosion and wear. The electrical conductivity of this alloy was not appreciably less than that of pure copper. These properties made beryllium-copper and similar alloys useful for the construction of springs for the moving parts of aero-engines and aircraft instruments, and in the manufacture of parts for tanks, guns, electric motors and shells. Owing to its non-sparking character beryllium-copper was used in making tools for work in explosives factories. Most of the beryllium consumed during the war went to the aircraft industry, much of it in the form beral, an alloy of beryllium and aluminium.

Most of the beryl mined in 1943-44 was obtained as a by-product of the mining of tantalite, with which it is closely associated. A considerable stock of beryl built up by the former owner of the mine at Wodgina, together with some produced by operations on behalf of the Commonwealth Government, amounting in all to about 925 tons, was exported to the United States. Beryl from this source also contained small but none the less important amounts of the extremely rare metal caesium.[7] At the conclusion of mining operations in 1944 all easily won beryl and tantalite in sight had been exhausted.[8]

Beryl was one of the first minerals to be studied at the Division of Industrial Chemistry, where small amounts of beryllium oxide were smelted with carbon and copper to make beryllium bronze.

Rutile. The stimulus of war not only hastened the establishment of a national survey of mineral resources, it also did much to spur on scientific investigation of methods for the more efficient use of known resources, especially those minerals for which Australian industry had so far found little or no use and of which there was a plentiful supply.

In the beach sands of the eastern coast of Australia are some of the world's richest deposits of rutile and zircon, minerals containing the metals titanium and zirconium. When these sands were first exploited, in the early thirties, little more was done than recover the minerals in the form of a crude mixed concentrate, which was then exported to the United States at the rate of many thousand tons a year.

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[6] H. G. Raggatt, "Australia's Mineral Industry in the Present War". Clarke Memorial Lecture delivered before the Royal Society of NSW, 23 Jun 1943.

[7] About 1 per cent.

[8] C. J. Sullivan, *Beryllium Summary Report No. 18*; Bureau of Mineral Resources; reprinted 1948. At this date geologists held the view that similar bodies of beryl might well be found at greater depths.

By 1939 one section of the industry had evolved methods based on the principles of flotation and differential magnetic separations, for the production of clean zircon concentrates of exceptional purity, and rutile of only a slightly lower grade.[9] In spite of this success, most of the minerals shipped overseas during the war continued to take the form of crude mixed concentrates.[10] A growing concern at the failure of the mining and chemical industries to take a more practical interest in exploiting these and other minerals resulted in the formation, within the Division of Industrial Chemistry, of the Minerals Utilisation Section.[1] This was a significant step towards a greater development of the country's internal resources. A few examples will illustrate the usefulness of the section's work during the war.

One of the principal uses of rutile was for coating rods for arc welding, where its function was to shield the electric arc from oxidation during welding and to produce a brittle slag which protected the cooling weld deposit. Most of the 400 tons of rutile consumed locally was used for this purpose.

Rutile, however, was a valuable raw material for chemical industry. It was the source of one of the best smoke-producing substances known—titanium tetrachloride. The Minerals Utilisation Section, by means of a pilot-scale plant, worked out details of a process for manufacturing the tetrachloride using locally mined rutile in place of imported, chemically prepared, titanium dioxide.[2] This process formed the basis of its subsequent large-scale production for the Commonwealth Government by I.C.I.A.N.Z. Once the demand for large quantities of titanium tetrachloride as a smoke producer diminished, the problem arose of finding other uses for reserve stocks. At least two interesting developments followed.

Firstly, the tetrachloride was used as a raw material for the extraction of the metal. The metallurgy of pure ductile titanium metal was not well developed anywhere until some years after the war; the manufacture of titanium powder of reasonably high purity was a fairly difficult operation.[3] The Physical Metallurgy Section in the Division of Industrial Chemistry, using a method based on the reduction of titanium tetrachloride with magnesium, made small quantities of the powder of 98 per cent purity, and showed that it was entirely satisfactory for removing the last traces of oxygen and nitrogen from already highly evacuated radio valves. At least one Australian valve manufacturing company (Amalgamated Wireless

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[9] W. R. Poole, "Zircon and Rutile from Beach Sands", Part I, *Chemical and Engineering Mining Review*, Vol 31 (1939), p. 365.

[10] The position changed after 1944 when the Department of Trade and Customs prohibited the export of mined crude concentrates.

[1] The section was put in charge of Mr R. Grenfell Thomas. See R. Grenfell Thomas, "Chemical Processing in the Australian Mineral Industry", *Society of the Chemical Industry of Victoria*, Vol 43 (1943), p. 483.

[2] F. K. McTaggart, "Production of Titanium Tetrachloride from Australian Rutile Sand", *Journal of the Council for Scientific and Industrial Research*, Vol 18 (1945), p. 5.

[3] Owing to its great affinity for oxygen and nitrogen, titanium metal at high temperatures must be handled in an inert atmosphere, preferably of helium or *in vacuo*. This, together with its high melting point, makes its production both difficult and costly.

Valve Co Pty Ltd) adopted this method for supplying its requirements of titanium powder.

This was the first important work done in Australia on the metallurgy of a metal which, on account of its lightness, strength and resistance to corrosion, seemed likely to become an important material of construction.

A discovery made by the Minerals Utilisation Section was the use of butyl titanate as a vehicle for various inorganic pigments such as zinc and aluminium powder in the formulation of heat-resisting paints. While striking results were obtained with the use of such paints, commercial development of these products was slow during the war. Subsequently the formulations were greatly improved by the Paints Section of the Munitions Supply Laboratories and industrial interest in the manufacture of butyl titanate abroad was initiated as a result of this work. The possibility of using synthetic titanium nitride as a bonded material for tipping cutting tools was also explored by the Minerals Utilisation Section. Somewhat inferior to tungsten carbide in hardness, the bonded titanium nitride was much cheaper to produce; its use in the war period did not go beyond the experimental stage.

Sulphur. No organised searches were made for new sources of sulphur. However, many deposits of pyrites were examined by officers of mines departments and the Mineral Resources Survey in the course of other investigations. When all the information from these sources was collated it became evident that Australia's resources were very large indeed and that they could meet all her sulphur requirements for a very long time.

Mica. Some minerals are valued not for any metals they may contain but for themselves. Mica, graphite, asbestos and quartz belong to this class. Though not consumed in large amounts, their uses were such as to render them of some importance, especially in war. Mica was unequalled as an electrical insulator, and had no substitute: no other mineral combined ready cleavage, flexibility, elasticity and optical transparency with high dielectric strength, electrical resistance and low thermal conductivity. During the war it was in greatest demand by the electrical industry, for making condensers. Efforts in various parts of the world before the war to make synthetic mica failed to yield the large single crystalline sheets found in nature.[4] In the electrical industry it was even more important than copper.

Of the commonly-occurring varieties of mica, muscovite was quite the most important. It occurs as crystalline plates which can be readily split into extremely thin, clear, practically colourless transparent sheets, some 60 square inches or more in area. In peacetime many different grades of mica, colour-spotted and stained as well as the highest grade, are used; in war the same was true except that the relative proportions of the

[4] Siemens in Germany successfully synthesised crystalline mica sheets by the end of the war, but only on an experimental scale.

grades used were reversed so that the highest grade was the one for which demand was greatest.

The most important deposits of mica were found in regions not easily accessible—in the Harts Ranges and along the Plenty River, 150 and 250 miles north-east of Alice Springs. Smaller deposits at Yinnietharra, Western Australia, and the Barker River were in similar out-of-the-way places. As happened in other branches of the mining industry, and for substantially the same reason—drift of labour from the mines—the output of mica fell seriously during the early part of the war—from about 30 tons a year to less than 10 tons in 1942. A Commonwealth Mica Pool formed in 1942 was at first unable to do more than attempt to stockpile and to conserve supplies by controlling distribution. Since large amounts were needed for the rapidly growing aircraft and electrical industries, it was imperative that it should not be diverted to less essential uses.[5] Manufacture of radiators, toasters and electric irons was therefore forbidden. This had the effect of increasing the cost of producing high-grade mica by taking away the outlet for inferior sheet.

Production of mica became the close concern of the Controller of Minerals, who in order to attract workers to the fields in the Harts Ranges and neighbouring country, arranged with the Director-General of the Allied Works Council to have reasonably good roads constructed and water supplies put down. Every encouragement was given to miners to return to the mines: motor compressors, jack hammers and other mining equipments were brought into the area and hired out by the Government on a rental basis; weekly transport was arranged to convey stores and mail, and wireless transmitting and receiving sets were installed at suitable mines. These conditions, together with a guaranteed price for mica, induced miners to return. Production climbed steeply, output rising to 50 tons a year of mica, principally muscovite of high quality. All these efforts were not sufficient to keep pace with the sevenfold increase in consumption of mica and it was fortunate that it was possible to bridge the gap by imports from India.

Quartz crystals. Quartz, though easily the most abundant mineral in the earth's crust, is seldom found in large deposits of well-formed crystals of any size. Only after the advent of radio-communication did quartz crystals possess sufficient technical applications to warrant an intensive search for them. They then assumed considerable importance because of their piezo-electric properties.[6] When distorted by mechanical pressure, differences of electrical potential are created on their surface. The reverse is also true: if a potential difference is applied to the opposite faces of a crystal a small change in shape, or distortion, will result.

The great demand for quartz crystals in war depended on their use to maintain constancy in the frequency of radio waves employed in communi-

[5] Fifty per cent of high-grade mica was used in the radio industry, 10 per cent in making spark plugs for internal combustion engines.

[6] Other crystals are known to be piezo-electric, but none is so durable and robust as quartz.

cation. Another but less common use depended on the fact that vibrating quartz crystals set in motion by high-frequency currents were the source of ultrasonic waves used in the underwater detection of submarines, and in depth recorders. The consequent greatly-increased demand early in the war exceeded the output of Brazil and Madagascar, the world's principal sources of supply. Anxious searches were made at the instigation of the Controller of Minerals for supplies in Australia. For a brief period, owing to the unprecedented demands of the Services, there was a possibility that ships, tanks and aircraft might not be adequately equipped with radio, so meagre were supplies of quartz crystals. Responsibility for investigating all known deposits and reported occurrences of quartz crystals was undertaken by North Broken Hill Ltd, which arranged for its consulting geologist, Mr Garretty,[7] to carry out surveys. Crystals were found in many localities but in only one was there a sufficient quantity of the high quality needed to warrant commercial exploitation. This was at Kingsgate, New South Wales, where the first efforts were concentrated on turning over old "dumps" left from mining operations for molybdenum begun during the 1914-18 war. Later, operations were transferred to the mines themselves—shafts that had been sunk into the pipes of an old volcano.[8] The yield of high-quality crystals from this source was not high. Nevertheless it was, for a time, Australia's sole source of supply.

Asbestos. Australia had always relied on oversea sources—principally Canada and Africa—for supplies of asbestos. For this reason the Mineral Resources Survey made a detailed assessment early in its history of the rather widespread but small Australian deposits of chrysotile. Efforts were first made to work deposits in Western Australia of chrysotile of a grade suitable for spinning the textiles used in heat insulation and fire proofing. From 1942 onwards small amounts of chrysotile mined in New South Wales were used in making asbestos cement products: plain and corrugated sheets and pipes for the building industry. In Tasmania an attempt was made to work a small deposit of chrysotile near Zeehan, but it proved to be uneconomic and was soon abandoned. Attention was then given to the very large deposits of crocidolite (another variety of asbestos) in the Hammersley Ranges in Western Australia, and the industry was begun at Wittenoon in 1943. Before much progress had been made with this mine African and Canadian producers, finding their European markets closed, began to offer increasing quantities to Australia. Nothing much came of this venture until some years after the war.

Graphite. Graphite, one of the naturally-occurring crystalline forms of carbon, was an essential component of dry batteries, foundry facings, crucibles and some types of refractory. It owed its use in these ways to its

[7] M. D. Garretty, DSc. Chief Geologist, North Broken Hill Ltd, 1939-46. B. Sydney, 23 Feb 1914.

[8] M. D. Garretty, "Notes on the Occurrence of Piezoelectric Quartz in Australia with Special Reference to the Kingsgate Field", Bulletin No. 13, Geological Series No. 4, Bureau of Mineral Resources, Dept of Supply and Shipping. See also: F. Canavan, "Piezo-electric Quartz", Bulletin No. 10, Misc. Series No. 4; and F. N. Hanlon, "The Etch Figures of Basal Sections of Quartz", *Journal and Proceedings of the Royal Society of NSW*, Vol 77 (1943), p. 40.

chemical stability and inertness. Over the years 1940-44 the proportion of Australia's requirements of graphite obtained from local sources rose from 3 to 40 per cent. Most local graphite came from mines at Uley and Koppio in South Australia and from Collinville in Queensland. Owing to the stringent requirements for the graphite used in batteries—only minute amounts of impurities could be tolerated—none of the Australian graphite could be used alone for this purpose. By blending with superior imported graphite it was possible to use a substantial amount of Queensland graphite in the battery industry. Attempts were made to improve the grade of Australian graphite, both by chemical and by physical methods.

One of the long-range problems undertaken by the Division of Industrial Chemistry was a study of the fundamental processes underlying flotation. Although Australian mining companies had done much pioneering work in the early part of the century on the large-scale application of flotation, there was still a great deal to learn about its scientific basis; but before going ahead with this it was natural that the division's attention should have been directed to *ad hoc* problems brought up by the war. One of these was the purification of graphite. Treatment by flotation enabled the purity of graphite to be raised to somewhere in the vicinity of 90 per cent, but though the carbon content was high enough the nature of the impurities that remained precluded its use in batteries. Chemical methods for removing impurities inaccessible to the flotation process of separation, were then pressed into service. Combination of the two methods of purification resulted in a graphite whose performance in dry cells was equal to that of the high-grade material imported from Ceylon. Owing to the inertia of the battery companies the application of this work came too late to have any direct influence on the use of Australian graphite during the war, but it was of permanent value in later years.

Monazite. Monazite, a minor component of the black sands of the East Australian beaches, is recoverable during the separation of zircon and rutile. Notable for the variety of products obtainable from it by chemical processes, monazite is a valuable source not only of thorium and cerium but also of a number of metals belonging to the rare earth family. When treated by a process worked out in the Minerals Utilisation Section, monazite proved a source of the rare earth fluorides used in the cores of searchlight carbons to give the arc its great brilliance, and also of mixed cerium group oxides for polishing optical components. The Division of Industrial Chemistry made substantial quantities of a special grade of rare earth oxide, mainly cerium dioxide, which it supplied to the Scientific Instrument and Optical Panel of the Department of Munitions. This material, the speediest and most effective of all polishing powders, played a useful part in the production of optical munitions.

CHAPTER 6

RAW MATERIALS: CHEMICAL INDUSTRY

CHEMICAL industry, on which almost all other industries are dependent in some way, is one of the key industries in a country's economy. The trends followed by the Australian industry during the war were mainly those dictated by the need for greater self-sufficiency. That a rapid general expansion occurred in the industry is clearly borne out by statistics: over the war years the number of factories increased from 238 to 362; value of the output from £7,000,000 to £19,000,000, and the number of employees from 5,346 to 10,530.[1] The many developments in the manufacture of drugs, plastics and explosives were made possible by the rapid growth of heavy chemical industry that took place during the late thirties—mainly in the course of the industry's normal peacetime development, but no doubt accelerated by the threat of war.

From such simple raw materials as water, air, salt, limestone, sulphur, coke and rock phosphate, chemical industry manufactured the mineral acids and alkalis which, being in most general use and therefore required in large quantities, were known as primary or heavy chemicals. These in turn served as raw materials for making chemicals a little more complex in character, sometimes known as secondary or intermediate chemicals, such as phenol and aniline, from which finally came the most complex substances of all—drugs, dyestuffs, explosives and vitamins.

As a fairly general rule the obstacles in the way of setting up new chemical industries in Australia were economic rather than technical. Australian chemical industry owed a great deal to the British and American firms which were able not only to provide technical knowledge but also to survive the economic hazards that so often threatened the early growth of an industry. Whereas British chemical industry, the forerunner of all others, was born of the demand for chemicals needed in the finishing of textiles, the Australian industry grew out of the demand for chemicals consumed in primary industries—fertilisers for agriculture, and explosives for mining, quarrying, the building of roads and the clearing of forests. Early chemical industry in Australia was thus mainly concerned with the production of mineral acids essential to the manufacture of fertilisers and explosives. Although the raw materials were of a simple character, there was at first almost complete dependence on imported supplies: on Sicilian sulphur and on Chilean nitrates. In many countries the consumption of sulphuric acid has been taken as a yardstick of industrial activity, but in Australia, where an unusually large proportion (between 80 and 90 per cent) of the sulphuric acid consumed was used for making super-

[1] *Directory of Australian Chemicals*, issued by the Division of Industrial Development, Department of Post-War Reconstruction (1948).

phosphate and other fertilisers, the growth of chemical industry closely paralleled the development of agriculture.[2]

Mineral acids. By the beginning of the second world war about 65 per cent of the Australian output of sulphuric acid was based on imported elemental sulphur (brimstone). The remaining 35 per cent was obtained from sulphur dioxide formed during the roasting of zinc sulphide concentrates and iron pyrites, and to a small extent from the by-products of gas works.

Since additional quantities of sulphuric acid would be needed in war time for increased production of explosives and steel, and since it was imperative at the same time to maintain food supplies at their customary levels, dependence on outside supplies of native sulphur was a vulnerable spot in the material basis of Australia's economy. There was far more sulphur in the sulphide ores mined each year than was used in the form of sulphuric acid, and although some of this ore was exported as such and some sulphide sulphur was used for acid manufacture, much of it, in the form of flue gases, was allowed to go to waste in the atmosphere. The principal reason why these sulphide mineral sources of sulphur were not more fully utilised was an economic one.[3] It cost more, in spite of a government bounty,[4] to make sulphuric acid using iron pyrites or zinc sulphide concentrates as a source of sulphur than it did to make it from imported elemental sulphur. Nevertheless under the influence of wartime conditions the amount of sulphuric acid made from local sulphide ores rose from 35 per cent in 1939 to 67 per cent in 1944. Thereafter it fell away for some years, reaching 36 per cent by 1955.

The greater part of sulphuric acid produced in Australia at this time (about 80 per cent) was made by the chamber process—a method which permitted the use of roaster gases from metallurgical operations. It was not necessary to purify these gases to the same degree as would have been necessary for the contact process. While acid made by the chamber process was neither as pure nor as concentrated as that made by the contact process, it served well enough for the manufacture of superphosphate.

Increase in the use of sulphur roaster gases was achieved mainly in plants using the chamber process, but since the acid so produced was not suitable for the manufacture of explosives, the improvement in the defence position was not as great as might appear from the figures quoted above. In order to make certain of supplies of sulphuric acid of a grade suitable for the manufacture of explosives, large stocks of imported elemental sulphur were built up by defence authorities in the years 1937-39. This is

[2] The manufacture of superphosphate began in 1878 in the works of Cuming Smith & Co, Yarraville, Vic. Manufacture in NSW followed in 1880 by Elliott Bros.

[3] The fact that it was both inconvenient and costly to transport sulphuric acid and that it was not easy to bring rock phosphate to the site of some sulphide roasting plants, was responsible for much sulphur dioxide being allowed to go to waste.

[4] Discontinued in October 1939.

evident from the accompanying table, showing statistics of the importation of sulphur and the manufacture of sulphuric acid.

Importation of Sulphur and Manufacture of Sulphuric Acid

Year	Sulphur Imported (tons)	Sulphuric Acid (tons)
1938	141,796	498,288
1939	115,100	489,493
1940	105,345	369,816
1941	77,818	362,996
1942	41,032	270,161
1943	32,433	219,983
1944	28,233	237,013
1945	46,063	333,013

Several factors operated to ease possible danger from a complete loss of oversea supplies of elemental sulphur. Diminution in the supplies of imported rock phosphate meant that less acid was required for the use of superphosphate. A further lessening of the demand for sulphuric acid was brought about by the introduction of a more modern method of making nitric acid for explosives. Hitherto nitric acid had been made by treating Chilean sodium nitrate with sulphuric acid; the new process, involving the oxidation of ammonia, did away with the need for sulphuric acid except for the operation of concentrating the nitric acid.

Elemental sulphur could have been extracted from roaster gases had it been necessary. The recovery of sulphur from this source was being carried out in different parts of the world and was considered for Australia, but oversea experience indicated that the prospects of economic success were so slender that no firm here could be induced to undertake it.

Early in 1939 the Commonwealth Fertiliser and Chemical Company at Yarraville, Victoria, the largest producer of sulphuric acid in the country,[5] began to step up the production of two substances closely related to sulphuric acid, namely oleum[6] (fuming sulphuric acid containing more sulphur trioxide than corresponds to the formula H_2SO_4), in which form the acid was used in the explosives industry, and chlorosulphonic acid (needed among other things for the manufacture of sulphonamides). Taken as a whole, the sulphuric acid industry had by the time war broke out reached a size and stage of development that gave little or no anxiety so far as the manufacture of explosives and other munitions was concerned, and it remained that way throughout the war.

The position was not so satisfactory with nitric acid, the second important mineral acid of heavy chemical industry. In 1939 its manufacture was not only entirely dependent on imported nitrates but was on a scale too small to permit the manufacture of explosives in the quantities likely to be required in war. Nitric and sulphuric acid occupied a key position in the explosives industry, where in the form of a mixture known as

[5] This company was formed in 1929 as a result of a merger of four large superphosphate manufacturing companies: Cuming Smith, Mt Lyell, Wischer and Federal Fertilisers.

[6] This was usually in the form of 20 per cent oleum which is equivalent to 104.5 per cent H_2SO_4.



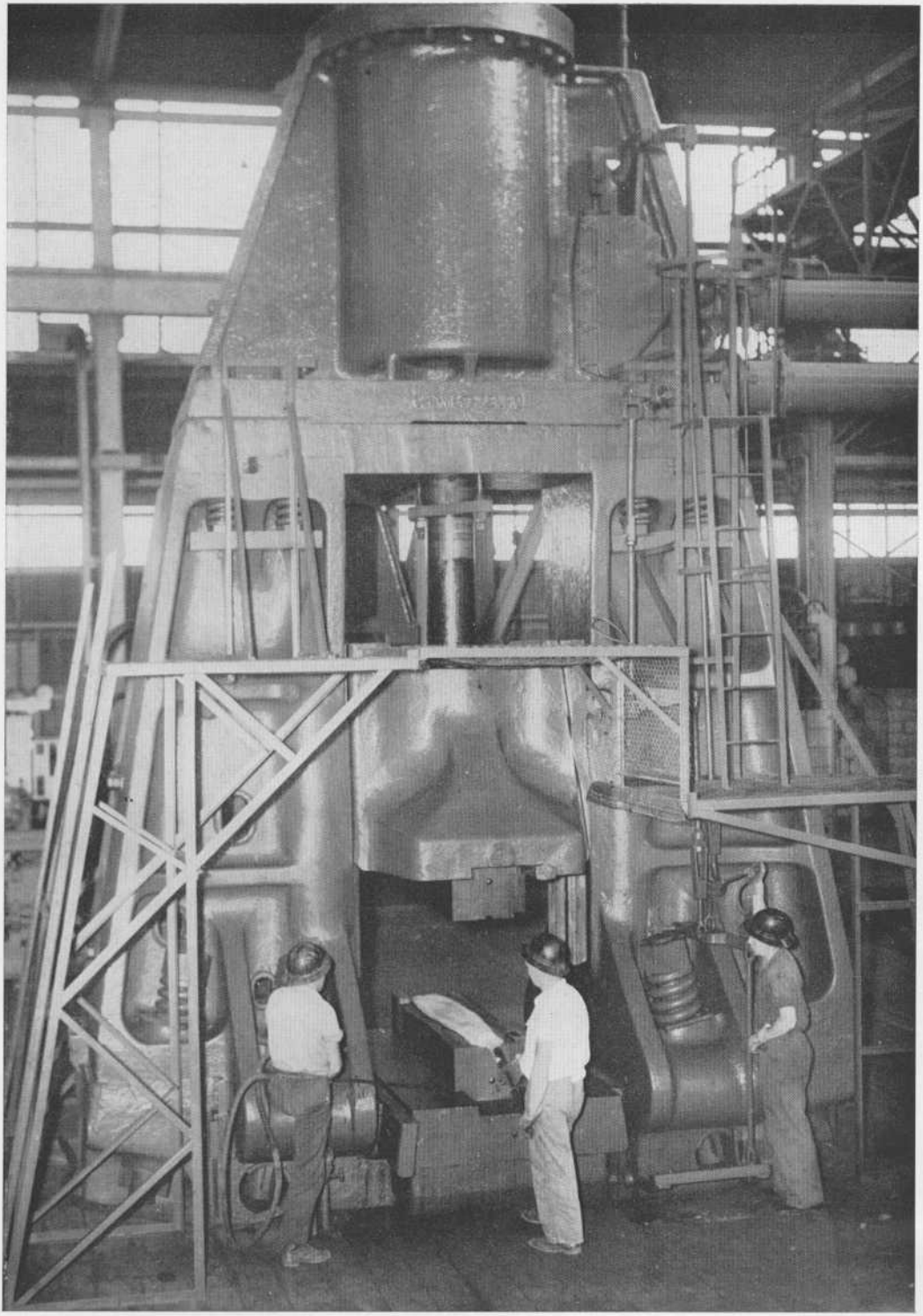
(*News and Information Bureau*)

A "book" of flawless mica mined in Central Australia. This "book" will yield sheets of up to 270 square inches, compared with the average of 3 to 6 inches.



(*News and Information Bureau*)

Australian rutile mined at east coast beaches provides the raw material for the metal titanium and for other metals of commercial value.

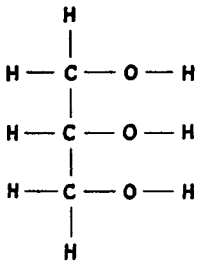


(*Australian Aluminium*)

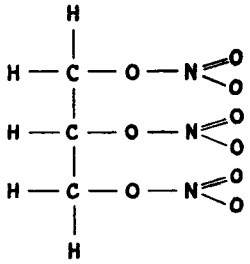
35,000-pound Drop Hammer.

"nitrating" acid they were used in the manufacture of practically every kind of explosive, commercial and military alike.

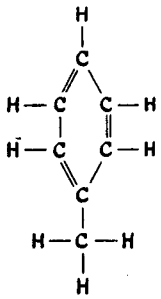
Other raw materials for the explosives industry were derived from such energy-rich materials as fats, carbohydrates, coal and petroleum. Glycerine from fats or sugar, and toluene from coal tar or petroleum were among the most common starting materials for making explosives. The chemical energy of these two substances and of many others could be enormously enhanced by introducing into their molecules, by the process of nitration, groups of atoms commonly known as nitro groups ($-NO_2$). The molecular changes involved in the conversion of glycerine and toluene to nitroglycerine and trinitrotoluene (T.N.T.), two of the most important explosives, are indicated in the accompanying diagrams.



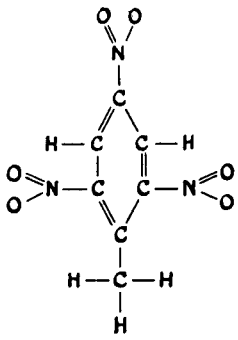
Glycerine



Glyceryl trinitrate or Nitroglycerine



Toluene



Trinitrotoluene or T.N.T.

By virtue of their loose attachment to the molecules of glycerine (or toluene) and the ease with which oxygen atoms were freed, nitro groups infected the explosive molecules with such instability that once they were disturbed, sometimes by no more than mechanical impact, they collapsed completely and instantaneously with the liberation of much heat and large volumes of gas.

From the time of its inception in 1874 to the outbreak of the second world war, the small Australian explosives industry relied upon the importation of sodium nitrate from Chile as a source of nitric acid. The chain of events which led to Australia's independence of nitrates from this source may be traced back to the war of 1914-18. That war taught industrialists of Great Britain the value to a country's defence of a highly organised, well integrated chemical industry. The British industry had had to import Chilean nitrate for explosives and fertilisers and, in 1914, had been unable even to dye the uniforms of the "first hundred thousand" in a fast khaki.

Two men of great vision, Lord Melchett and Sir Harry (later Lord) McGowan, convinced of the need for pooling the resources of British chemical industry and integrating its activities in order to bring about

efficient manufacture, marketing and research on a scale impossible to individual companies, began to plan along these lines. In 1926, as a result of their initiative, Imperial Chemical Industries Ltd was formed by a merger of Nobel Industries, United Alkali, Brunner Mond and British Dyestuffs. At the time of the United Kingdom merger the Australian branches and agencies of the individual members of the merger were gathered together to form Imperial Chemical Industries (Australasia) Ltd. The name was later changed to Imperial Chemical Industries (Australia and New Zealand) Ltd. A majority interest in the Australian company was retained by I.C.I. in England.

During the first world war Germany made herself independent of Chilean nitrates (the principal world source of supply) by developing a cheap and efficient chemical process for making nitric acid from nitrogen of the air, and thereby did much to lessen the effect of the blockade. This process, invented by Fritz Haber, consisted essentially of heating purified nitrogen (from the air) and hydrogen (from water) under high pressure (5,000 pounds per square inch) at a temperature of about 600 degrees centigrade in the presence of a suitable catalytic agent. Under these conditions nitrogen and hydrogen combined to form ammonia, which could be easily oxidised with oxygen (from the air) to form nitric acid. The process was so successful that after the war the British Government asked Brunner Mond and Company Ltd (which later merged into I.C.I.) to develop a similar industry. In the absence of details from Germany the firm was obliged to work them out more or less independently. It finally mastered the difficult technique of producing large-scale chemical reactions at high pressures, and in 1926 successfully established the synthetic ammonia industry at Billingham in Durham.

The first steps towards removing the dependence of Australian chemical industry on imported nitrates were taken towards the end of 1936 during a visit to Melbourne by Lord McGowan, when I.C.I.A.N.Z. informed the Munitions Supply Board that it had decided to embark on the manufacture of synthetic ammonia. The plan was to construct at Deer Park, Victoria, a plant similar in design to the one at Billingham. The intention in the first instance was to manufacture on a scale that would be sufficient to meet the needs for blasting explosives for industrial purposes, but at the same time the potential demand for nitric acid in war was kept clearly in mind.

Under its agreement with I.C.I. the Australasian company was entitled to full and free information with regard to, and the right to use in Australia and New Zealand, all patents, inventions and technical information concerning products being made in Britain. The formation of a strong technical staff in Australia kept up to date by constant intercommunication and exchange visits between England and other parts of the Empire, enabled Australian chemical industry to take full advantage of the arrangement. This was most fortunate, since facilities in Australian educational institutions for training chemical engineers were then quite inadequate for giving men the technological background needed to launch a process

as complex and as difficult as the synthesis of ammonia. Construction of the plant was begun in January 1939 and completed early in 1940. The plant was started up by a team under the direction of Mr Robb,[7] the first factory manager, and it was in production by April of the same year. Two subsidiary units were included: one for the oxidation of ammonia to nitric acid and a second for the synthesis of methanol (methyl alcohol). Both operated in close conjunction with the main process. Experience gained in operating the Deer Park plant was to prove of great value in the latter part of the war when additional ammonia plants were built. This subject will be treated more fully in the chapter on explosives.

The manufacture of hydrochloric acid, the third mineral acid of importance, offered no serious problem once sulphuric acid and chlorine industries had been established. A plant for the manufacture of chlorine and caustic soda from common salt by an electrolytic process, was erected at Yarraville by the Mount Lyell Chemical Company in 1918. In 1936, when the plant passed to the control of I.C.I.A.N.Z., its output was of the order of 800 tons of chlorine a year. This, the company's first venture into the local manufacture of chemicals other than commercial explosives, was a major step in its transformation from a merchandising company to the largest chemical organisation in Australia. From then on the capacity of the plant at Yarraville was gradually increased and by 1939 its output had reached 1,000 tons a year. Even with this and subsequent expansion up to 1942 the output of chlorine (3,200 tons a year) and of caustic soda (3,680 tons a year) was far from adequate for the country's needs.[8] Later in the war the company erected a second, more modern electrolytic chlorine plant at Matraville near Sydney, but it was completed too late to make any significant contribution to the country's wartime chlorine requirements.

The importance of chlorine lay in its use to manufacture bleaching agents for the paper and textile industries, degreasing solvents needed in the mass production of metallic articles, smoke-generating chemicals for the Services and antiseptics for public health authorities. Chloride of lime, or bleaching powder, found considerable use in the sterilisation of both civil and military water supplies. Its ability to counteract the vesicant action of mustard gas and lewisite, which it does by oxidising them to harmless compounds, would have made it an essential material in the event of gas warfare. It was for this reason that the Government entered into an agreement with I.C.I.A.N.Z. in 1939 to erect a plant capable of making 40 tons a week of chloride of lime.[1] Owing to some defects in the design of the plant and inability to secure a suitable grade of lime, the product was at first not altogether satisfactory, but with a few changes in the plant itself, chloride of lime meeting the Government's specification for 30 per

[7] A. G. Robb, BE. Works Manager, ICIANZ Ltd to 1946, Superintendent of Factories 1946-48, Controller, Development Dept, 1948-53, Personnel Dept 1953-55; Managing Director ICI(NZ) since 1955. Of Melbourne; b. Auckland, NZ, 7 Mar 1910.

[8] Caustic soda was also made at Osborne. This, when added to the Yarraville output, still fell short of the country's needs.

[1] Also known as chlorosene.

cent of available chlorine was eventually made. A later attack on the problem of making chloride of lime led to the adoption of a radical change in design and a new continuous enclosed plant, which went into service in 1943. Despite the fact that chloride of lime was one of the oldest known industrial chemicals, there was sufficient novelty in the Australian adaptation for it to be copied overseas. At one period of the war, large dumps of chloride of lime were built up in Northern Australia and New Guinea in case the Japanese should resort to the use of mustard gas. Fortunately they did not, and the dumps were never needed.

A shortage of potassium chlorate threatened the Australian match industry in 1941. The position might have become very serious had not I.C.I.A.N.Z., using its experience in the electrolytic chlorine industry, rapidly installed an electrolytic plant with sufficient capacity to tide the country over its period of shortage. A large amount of design and experimental work was carried out for the production of perchlorates, but the war had ended before a full-scale plant was brought into operation. Most of the developmental work on chlorates and perchlorates was carried out under the supervision of Mr Kable.[2]

Soon after the first world war a mission from Brunner Mond and Company had visited Australia to confer with a committee which had been set up under the chairmanship of Mr Grimwade[3] to inquire into the possibility of manufacturing alkalis. Brunner Mond also engaged Professor Woolnough[4] to make an independent survey and report, but as no completely satisfactory site could be found nothing came of either inquiry. A proposal made in 1931 to manufacture alkalis at Port Adelaide was investigated by a committee under Dr Rivett, whose findings were sufficiently encouraging to induce I.C.I. Ltd to send some of its experts to collaborate. A more suitable site was found at Osborne, on St Vincent's Gulf, and it was there that in 1934 I.C.I. decided to establish an alkali industry. In selecting this site proximity to fresh water and to the sources of two materials—salt obtained by the solar evaporation of brine on the shores of St Vincent's Gulf, and limestone from neighbouring quarries at Penrice and Angaston —was a deciding factor. Two other raw materials, ammonia and fuel (coke and coal), were obtained from the Adelaide Gas Works and Newcastle respectively. Ninety-five per cent of the money spent on building the alkali works was spent in Australia, only a few specialised items of equipment, such as turbines and compressors, being obtained from overseas.

The factory which was designed by I.C.I. Ltd and constructed and installed under the general supervision of Mr Hodgson,[5] assisted by Dr

[2] W. A. Kable, BSc. Chemist, Aust Gas Light Co. to 1941; Development Officer, ICIANZ Ltd, 1941-44, Superintendent Inorganic Div 1944-47, Asst Manager Production 1947, Development 1950, Senior Project Chemist for NSW 1952. B. Sydney 2 Feb 1914.

[3] Sir Russell Grimwade, CBE; BSc. Chairman Drug Houses of Aust. Company director; of Melbourne; b. Caulfield, Vic, 15 Oct 1879. Died 3 Nov 1955.

[4] W. G. Woolnough, DSc. Prof of Geology, Univ of WA, 1912-19; Geological Adviser to C'wealth Govt 1927-41. B. Brushgrove, NSW, 15 Jan 1876.

[5] G. P. Hodgson, BSc (Naval Architecture). Works General Manager, ICI Alkali (Aust) Pty Ltd, 1935-54; Member of Council, SA School of Mines, 1951-53. Engineer; of Cheshire, Eng; b. Queenstown, Ireland, 26 Jun 1892.

Garran[6] and Mr Kenny,[7] came into production early in 1940. Its rated output was 35,000 tons of soda ash, 5,000 tons of sodium bicarbonate and 8,000 tons of caustic soda, representing a major portion of the Australian requirements of these essential chemicals.

By 1939 Australian heavy chemical industry had developed to a stage where it could be expected to provide a sound foundation for the manufacture of the intermediate chemicals needed for making explosives, plastics and drugs. After the war broke out, both Britain and America became too engrossed in their own supply problems to make it safe for Australia to rely on them for chemicals.

The Government had not been unmindful of the difficulties under which chemical industries were labouring, especially the smaller and younger ones or those struggling to gain a footing in the market, and in 1940 it put into effect plans drawn up earlier on the recommendation of the Secondary Industries Research and Testing Committee, by establishing the Division of Industrial Chemistry at Fishermen's Bend, Victoria. The aims of the division were:

(*a*) to promote greater efficiency in established industries;
(*b*) to stimulate the establishment of new industries;
(*c*) to encourage the use of raw materials of Australian origin;
(*d*) to seek substitutes for imported materials; and
(*e*) to find uses for products not utilised.

The division was placed in charge of Dr Wark,[8] who immediately set about organising staff and procuring equipment—all slow processes at the best of times but made much more so by prevailing conditions. It was soon caught up in advisory work relating to the proposed production of aluminium, to the utilisation of tin and the recovery of tin plate, the synthesis of rubber and other problems raised by the war. Some of its experimental activities—those of the Minerals Utilisation Section—have already been referred to; others will be taken up later in this chapter.

The Department of Supply and Development and subsequently the Department of Munitions, saw to it that stocks of essential chemicals, either imported or made locally, were built up to meet the needs of the government explosives factories. The phenomenal growth of the manufacture of explosives, a highly specialised branch of chemical industry, will form the subject of a later chapter. Here we shall be concerned mainly with chemical industry in general, which will include those sections of it supplying raw materials to explosives factories together with the chemical industries essential to the manufacture of food, drugs, textiles, leather,

[6] R. R. Garran, MSc, PhD. Works Manager, ICI Alkali (Aust) Pty Ltd, 1940-50; Asst Controller, ICIANZ Alkali Group, since 1950. Of Northchurch, Eng; b. Melbourne, 3 Mar 1903.

[7] J. F. Kenny, BE, BSc. Chief Engineer, ICI Alkali (Aust) Pty Ltd, 1937-51; Senior Project Engineer Development Dept, ICIANZ, 1951-53, Senior Services Engineer since 1953. B. Auckland, NZ, 13 Feb 1909.

[8] I. W. Wark, PhD, DSc. Research Chemist, Electrolytic Zinc Co Ltd, 1926-39; Chief, Div of Industrial Chemistry since 1939. B. Melbourne, 8 May 1899.

paper, synthetic resins and paint, and the many other materials which played a part in arming the nation.

Australian chemical industry was not so strong that it could support a heavy defence program without cutting back on the consumption of chemicals used in civil industry. To make certain that defence industries were fully maintained with supplies of essential raw materials, control of chemicals was instituted—lightly at first but with increasing severity as the war progressed. Responsibility for this control rested with the Directorate of Materials Supply.[9] Where supplies were insufficient to meet the requirements of the munitions program and of the armed services, it was the directorate's function to apportion the materials available to the best possible advantage. When, on the other hand, supplies were not wholly absorbed in defence, the aim was to distribute the remainder to civilian industry by a system of rationing as fair and as advantageous as possible to the national welfare. Until June 1941 control of chemicals was limited to two important raw materials of the explosives industry: glycerine and toluene. Even these controls were not rigorously applied since they were not based on legal sanction.

After June 1941 the position underwent a complete change. As the heavy drain on the many essential chemicals required by munitions and aircraft increased, the Directorate of Materials Supply found itself surrounded by technical problems with which it was unable to cope. Mr Drake,[1] a senior scientific officer of the C.S.I.R., was appointed to assist the directorate to carry out a survey of chemical industry in order that it might have a sounder basis for making decisions. When it proved quite beyond the power of one man to achieve this in the short time required, the plan was superseded. An Industrial Chemicals Section was created within the Directorate of Materials Supply to exercise controls, coordinate the demands of munitions and other industries, and estimate the quantities of chemicals that should be imported.

Controls reached their greatest severity when, soon after Japan entered the war, they were designed to meet conditions of total blockade. At the height of its activity the Industrial Chemicals Section, with a staff of more than sixty technical and clerical officers, controlled more than 100 different chemicals, mainly those used directly in making munitions—armament chemicals, as they were called.[2] This demarcation of its field of action prevented the section from becoming as fully effective as it might have been. It did, at the request of different authorities, go beyond the field of armament chemicals, but as will be seen in the sequel, its powers were too limited to permit it to take effective action with regard to general chemicals. It gave assistance to the Medical Equipment Control Committee and to the

[9] E. H. Waters, "A General Account of Measures Taken with the Supply of Chemicals During the War of 1939-45". A report prepared for the Industrial Chemical Commission, 1945.

[1] E. J. Drake. (Served 1st AIF.) Principal Research Officer CSIR and CSIRO since 1939; Assistant Controller, Industrial Chemicals, Dir of Materials Supply, 1940-45; Scientific Attaché, Australian Embassy, Washington, 1953-55. Chemical engineer; of Melbourne; b. Kew, Vic, 16 May 1898.

[2] The first Control of Essential Articles (Materials) order was issued by the Department of War Organisation of Industry on 20 Feb 1942.

Division for the Control of Fertilisers in the Department of Commerce and Agriculture, in regulating the use of chemicals for making drugs and fertilisers.

Many sudden shortages of chemicals were caused by the armed services placing large orders for items which to them did not appear chemical in nature but which required large quantities of chemicals in their production. A synthetic vitamin, for example, produced in quantities which were measured in pounds, might require tons of raw materials and solvents in its manufacture. Similarly, the manufacture of sulphanilamide, aspirin and other drugs made heavy inroads on supplies of many industrial chemicals. As medical authorities also were not always fully aware of the probable effects of their demands, they often arranged for the large-scale manufacture of drugs without warning any other authority. Thus it occasionally happened that the Industrial Chemicals Section first learned of such projects as the result of an urgent demand for some scarce chemical required for making a drug of a high priority. Cooperation with the Medical Equipment Control Committee provided the solution to problems of this kind.

The exercise of controls was not simply a matter of devising of administrative procedures—it often involved the need for technical investigations as well. For example, control of calcium chloride, whose principal use in normal times was for refrigerant brines, became necessary when the United States Army Air Corps decided to use large quantities of it to lay the dust on and to help consolidate the surfaces of airfields in the drier parts of Australia. Until the alkali works of I.C.I.A.N.Z. were established at Osborne, Australia had depended entirely on importations. When it appeared certain that the original capacity of the Osborne plant (3,000 tons of calcium chloride a year) would not be sufficient to meet wartime requirements, it was increased to 8,000 tons. Even this would not have been enough if restrictions had not been placed on its use for civilian purposes. Reduction of civilian consumption was achieved by instructing operators of refrigerating plants requiring temperatures that did not go below 0 degrees Fahrenheit to substitute solutions of sodium chloride for those of calcium chloride. While this change saved a little calcium chloride it did not ease the situation to any significant extent. Sodium chloride alone could not be used in circulating brines intended for use below 0 degrees Fahrenheit since they would freeze solid. From the application of general physical principles it was known that this difficulty could be avoided by using mixtures of sodium chloride and calcium chloride. However searches of scientific literature revealed that no investigation had ever been made of the behaviour of such mixtures on cooling. The deficiency was promptly made good by experimental work carried out under the direction of Dr Iredale[3] in the Chemistry Department of the University of Sydney, which showed the maximum amount of sodium chloride that could be incorporated in a brine intended for use at any particular temperature. Thereafter all

[3] T. Iredale, DSc. Lecturer in Chemistry, Univ of Durham, Eng, 1920-27; Reader in Chem, Univ of Sydney. B. Castle Hill, NSW, 1897.

essential refrigeration plant was maintained in working condition on a consumption of calcium chloride approximately half that normally used.

At one period the armed services were demanding so much carbon tetrachloride for refilling fire extinguishers that supplies of this chemical for veterinary medicine, smoke mixtures, and civilian fire extinguishers were being jeopardised. United States Lend-Lease authorities were becoming extremely sceptical about the necessity for the large quantities being ordered. Private reports were received by the Industrial Chemicals Section that a major use of carbon tetrachloride was the illicit cleaning of uniforms. Although this was not admitted by the Service departments, they were persuaded to adopt the practice of adding a small amount of dyestuff to the carbon tetrachloride. This had no effect on its usefulness as a fire extinguisher but it did cause Service demands to drop away to such a small fraction of their former volume that it became possible to retain control of carbon tetrachloride.

Another sidelight on the complexities of the problem of controlling chemicals in war time is to be seen in the experiences relating to gases used in welding—oxygen and acetylene—both of which became very scarce at the end of 1941. Scarcity of acetylene was occasioned partly by the fact that much of the calcium carbide made at Electrona in Tasmania was being diverted from its ordinary use in the generation of acetylene to the production of magnesium. The real difficulty with the supply of gases for welding was in obtaining the steel storage cylinders. Commonwealth Industrial Gases Ltd, the firm solely concerned with the supply of welding gases, was unable to replenish its supplies of imported cylinders, and the position was aggravated by the fact that the Services failed to return empty cylinders. These difficulties persisted until the end of 1944 when British Tube Mills of South Australia began manufacturing the cylinders. The Services were not alone in their failure to appreciate the difficulties caused to manufacturers by not returning containers. Transport authorities within the Commonwealth would not give a sufficiently high priority to the carriage of stone jars and steel drums. On one occasion the production in New South Wales of glycerine for explosives nearly ceased owing to a scarcity of ferric chloride (used in its purification), which was caused by the reluctance of shipping companies to accept empty stoneware jars for return to Melbourne where the ferric chloride was made.

The same kind of thing occurred with drums used for the transport of nitrocellulose; the nitrocellulose plant of I.C.I.A.N.Z. at Deer Park was once on the point of closing for lack of drums caused by failure of users in other States to return them. These difficulties were usually overcome by the intervention of officers of the Industrial Chemicals Section. The principle that valuable containers should be returned to manufacturers was never, during the war, generally accepted by transport authorities, and the same case had often to be fought several times over as each fresh crisis arose.

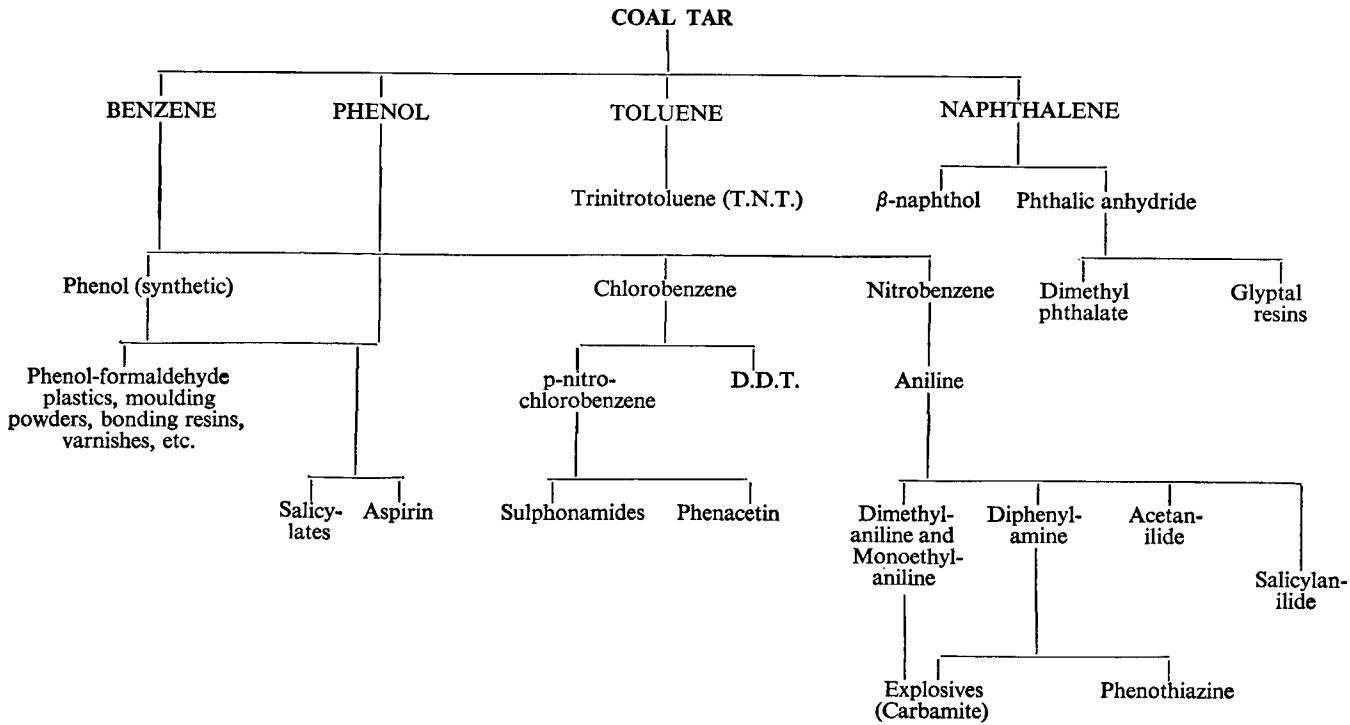
LARGE-SCALE MANUFACTURE OF ORGANIC CHEMICALS

Much of the early history of organic chemical industry in Australia was associated with the manufacture of explosives. Many of the raw materials used by this industry were either natural substances or derived from natural substances by fairly simple chemical steps. The manufacture of cordite during the first world war, for example, created a demand for glycerine, acetone, cellulose and methanol. For the next twenty years most organic chemical industries in Australia remained at this level of sophistication. It was not for lack of raw materials that this was so, for although Australia was without a petroleum industry she did possess deposits of coal and sources of carbohydrate materials from which important but relatively simple chemicals were derived. One of the principal reasons for the lag in development of organic chemical industry was that Australia's population was not large enough to support the manufacture, by chemical synthesis, of complex substances, such as drugs and dyestuffs, which were consumed in relatively small quantities. Large oversea chemical companies, as a rule, preferred to export their products to Australia rather than to set up small subsidiary manufacturing plants here. Under the stimulus of war large scale manufacturing processes involving chemical syntheses of a considerable degree of complexity were set up for the first time. It is impossible to say how quickly synthetic organic chemistry would have developed without the pressure of war, but there is no doubt that the war hastened its development.

In describing the wartime growth of organic chemical industries it is convenient to deal with them according to the source of raw material. Of these coal tar, a by-product of both the gas and the steel industries, was the most important.

Efficient development of the steel industry secured adequate supplies of cheap benzene first from the coke ovens at Newcastle and later from those at Port Kembla. Before the war practically the whole output of this potentially valuable chemical raw material was blended with motor spirit, so little demand was there for it in chemical industry. The wartime demand for explosives, plastics and drugs brought about a notable change and in 1940, for the first time, a small trickle of benzene began to flow to organic chemical industry. It was not long before it occupied the key position among the raw materials for this industry.

The steelworks' coke ovens could not meet the increased wartime demands for toluene (for the manufacture of T.N.T.) and reliance had to be placed on imports which, until the Japanese invasion, came mainly from Borneo. Plans were drawn up to make Australia independent of outside supplies of toluene by recovering it as a by-product of the operations of the Australian Gas Light Company's plant at Mortlake, New South Wales, but before they could be put into operation the heavy demand for toluene had ceased.


COAL TAR
BENZENE
PHENOL
TOLUENE
NAPHTHALENE
Trinitrotoluene (T.N.T.)
β-naphthol
Phthalic anhydride
Phenol (synthetic)
Chlorobenzene
Nitrobenzene
Dimethyl phthalate
Glyptal resins
Phenol-formaldehyde plastics, moulding powders, bonding resins, varnishes, etc.
p-nitro-chlorobenzene
D.D.T.
Aniline
Salicy-lates
Aspirin
Sulphonamides
Phenacetin
Dimethyl-aniline and Monoethyl-aniline
Diphenyl-amine
Acetan-ilide
Salicylan-ilide
Explosives (Carbamite)
Phenothiazine

Coal tar was a most complex material and contained other substances of interest to chemical industry besides benzene and toluene. The accompanying chart shows the four of the five so-called primaries (benzene, toluene, phenol, naphthalene) that came into prominence in Australian chemical industry during the second world war; it also indicates how the various explosives, drugs and plastics were derived from these basic raw materials.

One of the earliest attempts to exploit coal tar as a source of raw material for chemical industry was made by Timbrol Ltd of Rhodes, New South Wales. The firm's activities, which began soon after the 1914-18 war, were at first restricted to separating substances that occur naturally in coal tar. The early separations, aimed at isolating creosotes for use as timber preservatives, were crude and inefficient, but as time went on more modern practices were introduced and a gradually increasing range of products was obtained. By 1930, Timbrol Ltd was supplying the national requirements of phenol, solvent naphtha, tar acids, pyridine and other similar products derived directly from coal tar.

Realising that Australian chemical industry was unable to make the intermediate chemicals required in the production of primers for high explosives, stabilisers for cordite, essential chemicals for smoke mixtures and many other chemicals needed in munitions, the company in 1937 sent its general manager (Mr Peake[4]) to Britain, the United States and Germany in search of information and equipment. He returned with plans for the erection of plants for making nitrobenzene and aniline (from benzene), and for oxidising ammonia to nitric acid. It was not a simple matter to implement these plans. The plant at Rhodes had been built during the depression, from the after-effects of which the industry was only then freeing itself. There had not been time to gain sufficient financial strength to face up to extensive new undertakings.

Depressed prices for coal-tar chemicals from Britain created some difficulties but these were small in comparison with those arising from Germany's export drive with low-priced subsidised chemicals. This artificially-created depression, in effect a kind of cold war, did much to retard the growth of organic chemical industry in Australia.

But despite all these difficulties Timbrol Ltd went ahead with plans designed to bring into being chemical manufacturing processes likely to be of considerable importance to defence. The first of these was the manufacture of aniline and from it two closely related substances: monoethylaniline and dimethylaniline, both essential to several phases of the explosives industry. That the needs of the explosives industry had been correctly anticipated was evident when, on 1st July 1940, the company received a letter from the Director-General of Munitions asking for the state of progress of the work on aniline and its two derivatives. Timbrol Ltd was subsequently asked to erect an annexe for the Commonwealth Government and to go ahead with all speed with a plant capable of

[4] J. G. Peake. (Served 1st AIF.) General Manager and Director, Timbrol Ltd, since 1925. Of Sydney; b. Sydney, 20 Mar 1896.

making the three substances. The pilot plant for aniline was in operation by 30th September 1940 and by the following March monoethylaniline was being made at the rate of two tons a week. Full-scale operation was achieved by April 1942 and by that time there was no doubt that all demands for these chemicals would be met. At Albion, Victoria, I.C.I.A.N.Z. converted monoethylaniline (MEA) to carbamite (diphenyl diethylurea), a substance used to stabilise cordites. Dimethylaniline was used at the Explosives Factory at Salisbury, South Australia, for making the explosive tetryl (N-nitro-N-methyl-2,4,6 trinitraniline). While Timbrol Ltd was alkylating aniline by the customary process, Professor Earl[5] and Mr Hills[6] at the University of Sydney carried out investigations on the vapour phase alkylation with a view to discovering the most suitable catalysts. This method was tried on a pilot scale in 1944 but it came too late to have any influence on wartime output. It is of interest to note that a similar method was worked out independently in England and was there being transferred to a large scale as the war ended.

The manufacture of aniline was undertaken primarily because of its importance in the explosives industry. Aniline, however, had many other uses less directly related to war and it became evident that Timbrol Ltd could not do much more than supply the needs of the explosives industry.

In the course of their inquiry into the enlistment of Australian scientific resources for the war effort, Ashby and Vernon paid much attention to the chemical industry. They were greatly perturbed at what they found. No one appeared to be responsible for the overall coordination of the efforts of chemical manufacturers. The Industrial Chemicals Section of the Department of Munitions controlled the allocation and use of chemicals but it had no authority to arrange for new manufacture. It was, so it seemed to them, largely a matter of chance whether any other private firm would undertake the manufacture of aniline. Neither the Department of Munitions nor any other government department was interested in aniline beyond its direct use for munitions, and little guidance could be given to the manufacturers or the potential users of aniline since permission could not readily be obtained for the construction of additional plants.

Fortunately the situation had been brought to the notice of I.C.I.A.N.Z., which had had plenty of chemical experience of the kind that would be useful in manufacturing aniline. For some time it had been making nitrocellulose for "leathercloth" in its Fabrex Factory at Deer Park, and was in fact engaged in erecting plants for making nitrobenzene and paranitrochlorobenzene. The obvious course was to divert some of the nitrobenzene to the manufacture of aniline. A team of the company's chemical engineers, led by Mr Hamer,[7] introduced a continuous, highly-instrumented process

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[5] J. C. Earl, DSc, PhD. Professor of Organic Chemistry, Univ of Sydney, 1928-47. B. Adelaide, 18 May 1890.

[6] N. G. Hills, MSc. Research Scholar, Dept of Organic Chemistry, Univ of Sydney, 1938-47, Research Assistant 1948. B. Sydney, 5 Dec 1897. Died 29 Jun 1954.

[7] A. W. Hamer, MA, BSc. Vic Rhodes Scholar 1938; Technical Officer, ICIANZ, 1941, Factory Manager 1951-53, Technical Manager 1953-54, Controller of Development since 1954. Of Melbourne; b. Melbourne, 27 Nov 1917.

for making aniline known as vapour phase reduction, in which hydrogen—previously a discarded by-product of the chlorine caustic soda plant at Yarraville—was used as the reducing agent. An aniline plant with a capacity of 1,000 tons a year, the only one of its type in Australia and one of the very few in the world, began production in 1944. Some of this aniline was used for the manufacture of chemicals (mercaptobenzthiazole, for example) which were used to impart to natural rubber greater strength, longer life, and greater resistance to the distintegrating effects of sunlight, heat and oil. Much of the remainder was used for the manufacture of salicylanilide, a valuable fungicide, and of diphenylamine, which was required in the manufacture of carbamite and of phenothiazine, an important anthelmintic used in the sheep industry.

For a time it appeared uncertain whether any worthwhile quantity of diphenylamine could be diverted from the explosives industry for making phenothiazine. Phenothiazine was of no direct interest either to the Department of Munitions or to the Medical Equipment Control Committee. Its manufacture was cited by Ashby and Vernon as another example of the haphazard way in which chemical developments took place in the earlier part of the war. Not a great deal of it was required, the estimated consumption being of the order of 800 tons a year. Their main concern was that, since its manufacture appeared to have been left to chance, it might be undertaken independently by two or more firms, or worse still that a small firm hearing of a larger company's intention to manufacture might abandon its plans only to find the larger one forced to shelve its plans because of the pressure of other urgent work. It is, however, doubtful whether developments in some phases of chemical industry, at all events, were quite so haphazard as Ashby and Vernon imagined them to be. Unknown to them I.C.I.A.N.Z. had in fact applied to the Commonwealth Government in 1941 for permission to manufacture phenothiazine. This was granted, and the company manufactured it in sufficient quantities to safeguard the sheep industry, where it was used to effect an annual saving of some millions of pounds.

Naphthalene and phthalic anhydride. The Newcastle Chemical Company Pty Ltd was formed in 1940 jointly by the B.H.P. and I.C.I.A.N.Z. for the purpose of manufacturing chemicals essential to the steel industry, and for using the by-products of steelworks' coke ovens. Naphthalene was among the first of these by-products to be exploited; some was converted to phthalic anhydride, and much of the remainder to β-naphthol. The manufacture of phthalic anhydride was undertaken as a war measure because of the importance of this substance as a plasticiser for nitrocellulose lacquers for aircraft, and also for making glyptal resins and the mosquito repellent dimethyl phthalate. β-naphthol, on the other hand, was used as a fungicide and more importantly as the source of a chemical (α-nitroso β-naphthol) vital to the electrolytic zinc process as operated

at Risdon in Tasmania.[9] Another important derivative of β-naphthol produced at the Botany factory of I.C.I.A.N.Z. was phenyl-β-naphthylamine, one of the main anti-oxidants[1] used in the processing of rubber.

Previously imported mainly from Germany, β-naphthol was dangerously short in 1942. Failure of supplies would have seriously upset the zinc industry. Soon after the outbreak of war when, at the request of the British Government, zinc production was being stepped up, the Electrolytic Zinc Company had applied for a licence to import approximately two years' supply of α-nitroso β-naphthol. The Department of Trade and Customs refused the licence for the full quantity on the ground that an Australian company would shortly begin making it, but Australian manufacture of β-naphthol did not begin within the estimated period and for a while the resulting shortage had serious effects on zinc production.[2] Ashby and Vernon commented:

> The arbitrary import restriction placed on an essential chemical such as this indicates that there is a lack of technical advice available to the Government on the subject. This is understandable since the Ministry of Munitions, although concerned in the production of zinc and its usage, leaves the provision of chemical supplies essential for this production mainly in the hands of the zinc producing firms. Because of this there is a great danger that the Department of Trade and Customs may not be sufficiently well informed of chemical requirements to distinguish an importation essential to the war effort in a broad sense, from one of relatively slight importance.

Fortunately for the zinc industry the local manufacture of α-nitroso β-naphthol came in time to prevent any really serious dislocation.

Phenol. The importance of phenol lay in the fact that it was one of the raw materials for making phenol-formaldehyde resin or plastic (bakelite), which found extensive use for bullet tips and hand grenades and also in the manufacture of electrical fittings. Bakelite promised to be useful in other directions as a substitute for scarce metals such as copper, aluminium and tinplate. Other plastics were in general use at the time, but none appeared so suitable for most industrial and electrical uses as phenol-formaldehyde.[3]

Timbrol Ltd, the only firm in Australia recovering phenol from coal tar, was aware that in an emergency its output would not be sufficient to meet all requirements, and soon after the outbreak of war it began to make plans for the manufacture of synthetic phenol. Suitable raw materials were available: benzene (from B.H.P.), oleum (from Commonwealth Fertilisers and Chemicals), and caustic soda (from I.C.I.A.N.Z.). Timbrol submitted to the Capital Issues Board a proposal to manufacture, and obtained approval. In the meantime a representative of Monsanto Ltd was in the United States discussing a scheme for production with

[9] It was used to remove traces of cobalt from the aqueous zinc sulphate solution before electrolysis. Traces of cobalt and other similar metals seriously reduced the efficiency of the electrolytic zinc process.

[1] Chemicals designed to delay the "perishing" of rubber—in other words, to prolong its life.

[2] E. Ashby and J. Vernon, "The Enlistment of Scientific Resources in the War Effort" (1942), p. 89.

[3] A thermosetting resin, which, as distinguished from a thermoplastic resin, not only hardened when cured by heating but did not soften on re-heating.

his American principals. Monsanto decided to go ahead with its own production plans and also applied to the Capital Issues Board for the necessary approval. This was refused on the grounds that approval had already been given to another company. Nevertheless Monsanto, drawing on its own resources, went ahead, and in April 1942 produced the first synthetic phenol in Australia. Meanwhile Timbrol was so preoccupied with its work on the aniline annexe that it was unable to complete the phenol plant until late in 1942. Thus two plants were built almost simultaneously. This duplication of effort evoked some caustic comment from Ashby and Vernon. Their concern at what appeared to be another example of the serious lack of coordination in chemical industry, namely that no one at this period was planning to make formaldehyde, was however to a large extent unfounded: plans were in hand to manufacture it and its precursor methanol. That they were not so far advanced as might have been hoped was due mainly to the complexity of chemical industry. So far as military security was concerned there was little to be gained from the local manufacture of formaldehyde unless it was based on locally-produced methanol, which in turn could be most readily made as an adjunct to the manufacture of synthetic ammonia. Since the last named project was, during the war, principally the concern of the explosives industry, and since production of methanol would have to be at the expense of ammonia and therefore of nitric acid, it can be seen that the question of coordination was scarcely the sole concern of private manufacturers.

Chromium. In order to preserve some semblance of chronological order it is convenient at this point to digress from organic chemical industry to consider a group of chemicals which though inorganic in nature were intimately concerned in the treatment of materials organic in origin. The different compounds of chromium afford good examples of substances which were indispensable in war time, although used in very small quantities only, for the direct production of munitions. Dichromates of sodium and potassium and several other substances derived from them were irreplaceable in the tanning industry. Almost all leather for the uppers of boots and shoes was tanned by the chrome process because the alternative bark tanning process did not produce leather soft and pliable enough for this purpose. Specifications for military boots called for chrome-tanned leather uppers. Chromium compounds were also needed in the woollen industry for the dyeing of khaki and other fabrics.

Pre-war requirements in terms of sodium dichromate were estimated roughly as being:

Tanning	1,250	tons	per	annum
Munitions	200	„	„	„
Chrome pigments	300	„	„	„
Textiles	200	„	„	„
Total	1,950	„	„	„

The Department of Munitions, as a user of little more than one-tenth of the total, was therefore not seriously concerned about the general supply position. Towards the end of 1941 supplies of chromium compounds to the leather industry in Australia were most precarious and caused grave concern. Importation of chromium chemicals from the United States became almost impossible, since the industry there had been taken under government control and licences to export were being granted most sparingly.

Only low-grade deposits of chromite, the raw material for making chromium chemicals, had been found in Australia. All attempts by the Ore Dressing Section of the C.S.I.R. to beneficiate ore from a Queensland deposit were unsuccessful owing to the fact that impurities within the crystals of chromite were in a state of extremely fine dissemination. Fortunately chromite deposits, among the most suitable in existence as raw material for the manufacture of chemicals, occurred in the neighbouring French territory of New Caledonia.

Comparatively few firms in the world made dichromates, and these few kept the details of their processes secret, especially those concerning the first stage in which finely-ground chromite ore mixed with soda ash and lime was calcined. Published descriptions of experiments on this phase of manufacture conducted by the United States Bureau of Mines formed the basis of some early wartime experimental work in Australia. However after two years and a half of war no chromium industry had been started in this country. This was not for lack of warnings by the Tariff Board of the gravity of the position; it arose, Ashby and Vernon believed, from a "definite weakness in government chemical organisation". Private enterprise had failed to find sufficient inducement to enter this field of manufacture, they said, and the only alternative was government intervention to see that a plant was started. They found no government department so constituted as to be able to assume this responsibility. It was not the function of the Department of Supply and Development to initiate chemical manufacture such as this, and in any case it had no chemical section to deal with the problem.

The Department of Munitions had assumed a very efficient direction over the production of chemicals for its own use—the so-called armament chemicals—but no well-organised attempt had been made to arrange for the production of equally important chemicals for other essential industries. Some firms were willing to undertake projects of doubtful economic prospects from patriotic motives, but they naturally wanted to know how important the projects were to the war effort. No government organisation was empowered to reassure them on such matters.

It was this situation that led Ashby and Vernon in their report to the Prime Minister to recommend the appointment of a Director-General of Chemical Industry with power to initiate and direct new chemical industries as distinct from the activities of the Directorate of Materials Supply which, as we have seen, were almost entirely those of control and rationing. Their recommendation was not adopted. Instead another committee, known

as the Industrial Chemicals Committee, was appointed towards the end of 1942 and given executive powers.[4] It was to draw up a development program, assessing the degree of urgency attaching to each proposed manufacture; to promote the manufacture of chemicals needed in any way for defence, and if necessary to initiate investigations and development work directed towards this end. By the time the committee got into its stride only the most obstinate problems remained to be solved. One of its first objectives was to promote the manufacture of chromium chemicals, which it did by arranging for the Commonwealth Government to purchase 10,000 tons of raw material (chromite) from New Caledonia. Once supplies of raw materials had been assured, a company known as Chrome Chemicals (Aust) Pty Ltd, a subsidiary of the Australian Cream of Tartar Company Pty Ltd, began the erection of a plant at Parramatta, New South Wales, in May 1943. Design of the plant and pilot-scale experiments were carried out by the chemical and engineering staff of the Cream of Tartar Company working under the direction of the Technical Superintendent, Mr Marshall.[5] Production of sodium dichromate for tanning began in June 1944.

The conventional process for the manufacture of various chromium derivatives from chromite ore involved the use of sodium carbonate, which was in short supply in Australia at one stage of the war. For this reason the Minerals Utilisation Section of the C.S.I.R. explored the possibilities of alternative processes, and succeeded in working out a method based on digestion of the powdered chromite ore with sulphuric acid in the presence of a small amount of chromic acid as a catalyst. The resulting solution of sulphates was then oxidised electrolytically and the chromic acid crystallised out by concentrating the liquors. Chromic acid thus produced had a high degree of purity and was eminently suitable for use in preparing chromium plating baths, chrome green pigments essential in certain camouflage paints, chrome khaki dyes, and chrome tanning salts. The shortage of sodium carbonate had passed and the war was over before the acid process reached a stage where it could be translated to the commercial scale. The project was nevertheless carried to large pilot-plant scale by the C.S.I.R. For some years the C.S.I.R. and Chrome Chemicals worked together on the acid process. The company finally concluded that it was no cheaper than the conventional process and that there was therefore no justification for departing from established methods.

Methanol and formaldehyde. Methanol was used as a raw material for making formaldehyde and also for making certain explosives and substances such as methyl bromide, which was used in special fire extinguishers for aircraft. The distillation of wood, once the main source of methanol, was to a large extent superseded by the synthetic process employing coke,

[4] Members of the committee were: A. E. Leighton (Chairman); Dr I. W. Wark (Chief, Division of Industrial Chemistry, CSIR); Dr J. Vernon (Chief Chemist, Colonial Sugar Refining Co); E. J. Drake (Assistant Controller of Industrial Chemicals, Directorate of Materials Supply).

[5] J. L. Marshall. Research Chemist, Aust Cream Tartar Co Pty Ltd and Chrome Chemicals (Aust) Pty Ltd, 1942-47, Technical Superintendent since 1947. Of Sydney; b. London, 4 Jan 1909.

air and water as raw materials. At the period of the war when reliance had to be placed solely on imported supplies, which were becoming increasingly difficult to obtain, the firm of Elliotts and Australian Drug Pty Ltd, of Sydney, seriously thought of starting up a wood distillation plant near Narooma, New South Wales. The application of the distillation process to Australian timbers was thoroughly explored and although it would have yielded two additional valuable by-products—charcoal (for gas producers) and acetic acid—the venture was not launched on a commercial basis in New South Wales. The ever-present threat of competition from synthetic methanol was presumably the main deterrent. However a wood distillation industry was started at Wundowie, Western Australia, though not as an isolated activity. It formed part of the West Australian Government's scheme for setting up an iron and steel industry dependent on wood charcoal instead of the customary coke. The Industrial Chemicals Committee acted as adviser on this scheme, which was not begun, however, until towards the end of the war.

In the synthetic process for methanol, air and steam were passed over red-hot coke, yielding a mixture of hydrogen and carbon monoxide, often referred to as "synthesis gas". Methanol was then formed by allowing the two gases to react in the presence of a suitable catalyst, a process conveniently operated in conjunction with the synthesis of ammonia. It was first so operated in Australia by I.C.I.A.N.Z. at Deer Park in March 1944. Synthesis of ammonia began in 1940 but synthesis of methanol had to await construction of the additional plant.

Rather than wait for the plants at Wundowie or Deer Park to begin production, the Industrial Chemicals Committee exerted strong pressure to import a reserve stock of methanol. At the same time it did everything possible to smooth the path of Monsanto in its effort to build a plant for the manufacture of formaldehyde by the catalysed oxidation of methanol vapour. Operating with the stocks of methanol built up by the Government at the instigation of the Industrial Chemicals Committee, the Monsanto company began making the Australian requirements of formaldehyde in April 1944. The Monsanto process for making formaldehyde, based on practice in the United States, affords another example of a general trend in chemical industry away from methods involving working with batches of material and much handling of solids and liquids. Oxidation of methanol vapour was continuous, automatically controlled and much more convenient than the older batch processes. The way was now clear for the manufacture of synthetic resins.

Phenol-formaldehyde moulding powders. Most munitions products called for grades of synthetic plastic moulding materials with properties different from those required for their customary civilian use. Monsanto and Beetle Elliott Ltd, Sydney, who made all the phenolic moulding powders at that time, had to conduct fairly extensive investigations into the problem of producing these special wartime grades. Some of the items moulded from these plastics were: aircraft parts, small-arms parts, buttons, buckles,

fuse nose caps for anti-aircraft shells, transit plugs for filled shells, hand grenades, and anti-personnel mines. For hand grenades a special grade of fabric-filled, medium-strength powder was developed which saved considerable amounts of more valuable metals. Not only this, it lent itself readily to mass production because it could be rapidly moulded to accurately defined dimensions. Anti-personnel mines were made from phenolic plastics instead of metal so that when buried they could not be detected by the ordinary mine detector.

Industrial phenolic resins for special purposes, such as high-strength fabric-filled and paper-filled laminates for aircraft components and for food packages (instead of tinplate), were also supplied, in amounts shown in the accompanying table.

	Moulding powders	Industrial resins
1942-43 . .	289 tons	—
1943-44 . .	651 tons	29 tons
1944-45 . .	736 tons	87 tons
1945-46 . .	1,193 tons	55 tons

Ethanol. Ethanol or ethyl alcohol could be made by the action of yeasts on fermentable sugars, and since cellulose and starch could be converted to sugars by hydrolysis, the number of possible raw materials for its manufacture was quite large. They included:

(*a*) saccharine materials from sugar cane, beet molasses and fruit juices;
(*b*) starchy materials—from wheat, barley, oats, rice and potatoes;
(*c*) cellulosic materials from wood.

The climatic conditions of north-eastern Australia have encouraged a large sugar industry, which as early as 1875 became a source of alcohol. At the turn of the century the Colonial Sugar Refining Company began to operate at Pyrmont, near Sydney, a distillery which has been in continuous production ever since. In 1926 the Distillers Company Ltd of London and Edinburgh, together with a number of Australian sugar-milling companies, built a distillery at Sarina, Queensland, with an output of 2,000,000 gallons of alcohol a year. This was enlarged by the installation of a second 2,000,000-gallon still during the war. The Colonial Sugar Refining Company expanded its Pyrmont distillery in 1938 and opened another at Yarraville, Victoria, in 1940. Between them Australia's three distilleries were producing about 7,000,000 gallons of alcohol a year. About half this output went to chemical industries.

Alcohol was second only to water in the universality of its solvent action, for which reason it was widely used in the paint industry for polishes, lacquers and varnishes; it also formed the basis of a solid fuel which being light in proportion to its heating value was particularly useful under conditions of emergency, and therefore found considerable use in the army. Its potentialities as a raw material for organic chemical industry, which were just beginning to be exploited, rivalled those of benzene. It was, moreover, cheaper and more plentiful. There were ample supplies of alcohol for chemical industry. During the war a large proportion of

the output of alcohol (up to 35 per cent) was used as a motor fuel in mixtures containing four parts of petrol to one of alcohol. An account of an ambitious scheme to increase the production of alcohol for this purpose will be deferred until a later chapter.

Synthetic rubber. After the loss of the Malayan rubber plantations to the Japanese, serious consideration was given to the possibility of manufacturing synthetic rubber in Australia. A small committee appointed by the C.S.I.R. critically examined the requirements for a plant to produce 20,000 tons a year of the type of rubber known as Buna S, thought to be the most suitable in the circumstances. The committee estimated that it would require a considerable number (about 200) of chemists, chemical engineers and draughtsmen to design, erect and operate a plant of this size.[6] On the material side it was estimated that 4,700 tons of steel and 250 tons of copper would be required for constructional purposes, together with about 17,000,000 gallons of alcohol a year as raw material. It was decided that, critically short as rubber was, the venture was too costly, which, in the light of the failure of the power alcohol scheme, was a fortunate decision. Australia was able to augment her rapidly-diminishing supplies of natural rubber by importing synthetic rubber from the United States.

A technical mission comprising government and industrial representatives visited the United States in June 1944 to gather the latest information on methods of processing synthetic rubber.[7] Small-scale experiments on the use of synthetic rubber in Australia had begun as early as January 1944. After the return of the mission the use of synthetic rubber increased, reaching about 600 tons a month by the end of the war.

Acetone. Towards the end of 1939 Robert Corbett Pty Ltd of Lane Cove, New South Wales, completed a plant for making acetone by the fermentation process which had been developed by Chaim Weizmann in England during the war of 1914-18. The factory at Lane Cove used a strain of the original Weizmann organism (sub-cultured) in the fermentation of molasses to produce a mixture of acetone and butanol in the ratio of about one part of acetone to two of butanol. The output of acetone from this plant was, however, not enough to make Australia self-sufficient in the event of war.

Importation, which was fairly easy in 1940, became very difficult in 1941 and advice from overseas promised no improvement in supply. In anticipation of a greatly increased demand for acetone for making cordite and smokeless powders and as a solvent for acetylene, the Commonwealth Government entered into an agreement with the Colonial Sugar Refining Company (C.S.R.) for the erection and operation of an annexe costing

[6] H. H. Hatt, W. E. Purnell and I. W. Wark, "Report on Proposal to Manufacture Synthetic Rubber in Australia". CSIR Report Dec 1942.

[7] Synthetic rubber required methods of treatment completely different from those employed for natural rubber.

about £354,000 to convert alcohol to acetone. This led to the formation of a company known as Acetone Pty Ltd, in which British Industrial Solvents (a subsidiary of the Distillers Company Ltd, London), the Colonial Sugar Refining Company Ltd, and Robert Corbett Pty Ltd were shareholders. The manufacturing process was licensed to the Commonwealth Government by British Industrial Solvents Ltd, which also provided the necessary technical assistance. The process, which was continuous, consisted in heating a mixture of aqueous alcohol vapour and air over a catalyst of Swedish spongy iron. The Research Department of the C.S.R. Company successfully developed alternative catalysts from locally obtainable materials in case supplies of the Swedish catalyst were interrupted; however, no such shortage occurred.

In a little more than 10 months the factory, with an estimated capacity of 3,000 tons of acetone a year, was completed; from October 1942 when it began operation, self-sufficiency in acetone was assured. The plant had not reached more than about 40 per cent of its designed capacity when the Government ordered that it be closed down because the need for additional supplies of acetone in the explosives industry had passed. Eclipse of the plant was only temporary: it was brought back into production soon after the war as one of a group of industries concerned with the manufacture of acetic acid, acetic anhydride and cellulose acetate for the rayon and wrapping industries.

Xanthates. In the concentration of copper, lead and zinc ores by flotation, finely ground ore consisting of mineral particles and useless material such as silica, was mixed with water to which had been added a frothing agent, and a substance known as a "collector". When air was blown through the mixture mineral particles adhered to the surface of the bubbles, leaving the silica and other worthless gangue material behind. Of the many substances that had been tried as collectors none had proved so successful as the xanthates introduced in the United States during the late twenties. It was not long before these substances were taken up by the mining industry in Australia, and Timbrol Ltd, searching for opportunities to enter the organic chemical industry, decided to undertake their manufacture.

There was no great technical difficulty in making xanthates from alcohol and imported carbon disulphide, and steady progress was made in their manufacture and sale until, just before the war, subsidised German chemicals began to flood the market. It is true that for a while some trouble was experienced in attaining standards of quality equal to those of imported products. Only by the support, goodwill and commonsense of some of the mining companies, who foresaw that if these plants were closed down, the metal-extracting industries might in the event of war be seriously disorganised, was Timbrol able to maintain this phase of its activities and ultimately reach a satisfactory standard of quality.

Carbon disulphide was originally made at Yarraville, Victoria, first by Commonwealth Fertilisers and later by I.C.I.A.N.Z. As its use for the

extermination of rabbits declined and the demand for xanthates grew, the transport of large quantities of this inflammable liquid became more cumbersome and, mainly for this reason, I.C.I.A.N.Z. decided to install a plant at Botany, New South Wales. As a result, Timbrol increased its output of xanthates.

Other substances whose manufacture was either promoted or initiated by the Industrial Chemicals Committee included α-naphthyl-thiourea (a newly introduced, highly effective, rat poison), carbon black, and aluminium oleate. Laboratory work designed to assist local production of α-naphthyl-thiourea was carried out by the C.S.I.R. Division of Industrial Chemistry at Fishermen's Bend, Victoria. Commercial production was undertaken by Timbrol Ltd, who supplied the armed services with many tons of this remarkably specific poison for use in rat-infested tropical areas. No other substance appeared to be so toxic to rats and at the same time so harmless to other mammals as α-naphthyl-thiourea; it was unfortunately not the perfect specific since sooner or later the rats learned to avoid it.

Paper. Cellulose, one of the main products of plant growth, seldom occurs in anything like a pure form; it is always accompanied by other substances which differ considerably from one kind of plant material to another. Cotton, for example, contains about 90 per cent of cellulose, but as about two-thirds of the remainder is water it is one of the purest forms of natural cellulose. At the other end of the scale, woods and grasses contain between 40 and 60 per cent of cellulose. For many of the purposes to which cellulosic materials were put this heterogeneity was no drawback —it might be a considerable advantage. In the textile industries, fibres of cotton, flax and hemp were used without the necessity of subjecting them to extensive chemical treatment. Before wood cellulose could be used in making paper it had to be freed from many extraneous substances. Similarly, before cellulosic materials could be used to make explosives and lacquers, they had to undergo rigorous chemical purification. This was particularly true of explosives, where purity of materials was of the greatest importance. Impurities in cordite, for example, might endanger its safe storage.

Industry was slow to exploit the large quantities of cellulose obtainable from the hardwood forests of Australia. The reason for this may be found in the peculiar characteristics of the cellulose fibres that make up hardwoods. The principal difference between the soft woods (conifers) generally used for paper making in Europe and North America and the Australian eucalypts, is that the fibres which make up the wood of the latter are much shorter than those of the former. Basically, the process of making paper consisted of streaming a pulp of cellulose fibres over a wire cloth to form a continuous felted sheet, and then passing this between hot rollers to consolidate and dry it. In making the cheapest kind of paper (newsprint) no attempt was made to free the cellulose fibres from the

lignin which always accompanied them in the wood. The wood was simply ground to a pulp under water by means of special grinding stones. Paper from pulp of this kind had relatively little strength and little permanence, but it was quite suitable for newspapers.

For a long time it was believed that the fibres of eucalypts were too short for paper making, that they could not be felted together to give a paper sheet of any useful strength. Experiments to test the possibilities of Australian timbers for paper making were begun by Messrs Boas[8] and Benjamin[9] at the Perth Technical College as far back as 1918, under the auspices of the Institute for Science and Industry. At first experiments were directed towards making a chemical pulp, that is, one of fairly pure cellulose freed from lignin and other impurities. Experts brought out from England and the United States pronounced the possibilities of using eucalypts for paper making to be very remote indeed.

In spite of these and other discouragements the Australian experimenters persisted with their work and by 1930 had shown that a good mechanical (newsprint) pulp could be made from *Eucalyptus regnans* (swamp gum or mountain ash), Australia's tallest tree. Experiments showed that shortness of fibre was not necessarily an impediment to paper making providing that the fibre was correspondingly small in diameter: the ratio of the length of the fibre to its diameter was the determining factor. By combining this mechanical pulp with a small amount of chemical pulp from the same tree, a satisfactory paper could be made on the laboratory scale.

Newspaper concerns then began to take an interest in the project, the Melbourne *Herald* sponsoring further work in 1932. Some 2,000 tons of swamp gum timber was sent to Ocean Falls Newsprint Mills in British Columbia, the largest of their kind in Canada. Here large-scale tests brought to light troubles that had not manifested themselves on the small-scale work. The resulting paper, instead of being near white, was a bluish grey which was traced back to the fact that the unusually large amount of tannin and acetic acid present in swamp gum wood reacted with the iron and steel of the machinery used in converting it to paper to form iron tannate, a colouring matter often present in ink. It became evident that a careful choice would have to be made of the construction materials in any new plant. Stainless steels, special bronzes and acid-resisting concretes would have to be substituted for the materials customarily used.

As these were difficulties that competent chemical engineers could be counted upon to surmount, a group of interests representing leading Australian newspapers decided to form a company to be known as Australian Newsprint Mills Pty Ltd.[1] In selecting a location a number of important considerations had to be borne in mind: it must be on deep water and

[8] I. H. Boas, MSc. Officer-in-Charge Forest Products Lab, Advisory Council for Science and Industry 1919; Chief, Div of Forest Products, CSIR, 1929-44. B. Adelaide, 20 Oct 1878.

[9] L. R. S. Benjamin, CBE. Officer i/c eucalyptus wood pulp and cellulose investigations of Inst of Science and Industry, and CSIR, 1919-28; General Superintendent Aust Newsprint Mills Ltd, Boyer, Tas, since 1937. B. Ayr, Qld, 30 Apr 1892.

[1] The companies represented were: John Fairfax & Sons Pty Ltd; The Herald and Weekly Times Ltd; Associated Newspapers Ltd; Advertiser Newspapers Ltd; News Ltd; Queensland Newspapers Pty Ltd; Davies Bros Ltd; West Australian Newspapers Ltd.

close to forests abounding in *Eucalyptus regnans*; it must have a good supply of water of high purity, and power must be readily available. Boyer, on the River Derwent in Tasmania, came nearest to fulfilling these requirements and was therefore chosen as the site for the new mills. Even with all the previous laboratory and small-scale experience gained in Australia, it was necessary to draw on oversea experience in the construction of the mills themselves.

The plant at Boyer, designed under the supervision of Mr R. P. Sandwell, a Canadian engineer with extensive experience in the manufacture of newsprint, came into production in March 1941 in time to meet a crisis then arising in the newspaper world. Owing to difficulties with the importation of newsprint, daily newspapers were forced to accept rationing; imports were reduced by 35 per cent in July 1941, and in November 1942 the reduction was increased to 72 per cent, in order that as much shipping as possible could be made available for essential munitions supplies. By this time the Boyer mill began to make a significant contribution to the requirements of the newspaper industry. The production figures were:

	Tons
1941 . . .	4,776
1942 . . .	20,150
1943 . . .	21,294
1944 . . .	26,749
1945 . . .	24,895
1946 . . .	28,128
	125,992

Imports during the same period amounted to approximately 140,000 tons.

In the late thirties a paper mill was brought into operation on the shores of Emu Bay at South Burnie, Tasmania. Associated Pulp and Paper Mills Ltd began during 1939 to treat Tasmanian timbers by the bleached soda process to make a chemical pulp, which differed from the mechanical pulps used for newsprint in that it was formed by freeing cellulose fibres from all accompanying materials—the tannins, lignins and hemicelluloses —that cemented them together in wood.

Associated Pulp and Paper Mills Pty Ltd produced not only the bulk of Australian requirements of fine writing and printing papers, but also those of Allied forces in the South-West Pacific Area at a critical period of the war when oversea supplies of paper had almost dried up. The successful operation of this industry was, like the newsprint industry, the result of many years' preparation.

An account of Australian Paper Manufacturers' achievements in providing cellulose for the wartime explosives industry will be deferred to a later chapter.

Flax. Though the production of flax fibre, a cellulosic material essential in war (as well as in peace), was not strictly speaking a chemical industry, it is appropriate to consider it briefly at this point. Flax was used in the

manufacture of many articles of equipment for the fighting services—military boots, clothing, parachute harness, cordage and canvas. Flax had not been successfully grown in Australia on any scale until 1936 when Flax Fibres Pty Ltd made a small start with 200 acres. This increased to 2,000 acres by 1939, but still the bulk of flax used in Australia was imported. With government backing the company was in the course of increasing its crop to 8,000 acres, which would yield about half of Australia's needs, when in June 1940 Belgian supplies were cut off. Faced with the task of supplying all her own needs, and with a request from the United Kingdom for the yield from 12,000 acres, the Government was forced to act swiftly. As Flax Fibres Pty Ltd were unable to meet these new demands, the Government leased the company's business and set up a Flax Production Committee[2] in July 1940 to arrange contracts with farmers, supply the seed, and build and operate the mills. The area devoted to flax finally amounted to 60,000 acres, distributed throughout Victoria, Western Australia and Tasmania.

Very little had been done to develop the processing of flax, and consequently many technical problems were encountered. Those relating to agriculture and biology were handled by the State Departments of Agriculture and by the University of Sydney; those relating to the retting of flax (a process whereby the fibres of the stalk of the flax plant were separated from one another by bacterial attack on the material cementing the fibres together) were studied by the C.S.I.R. Division of Forest Products in Melbourne; those related to mechanical harvesting of the crop and processing of the fibres became the concern of H. V. McKay Massey Harris Pty Ltd, of Sunshine, Victoria. Retting, a slow process usually carried out by exposing the fibres to bacterial attack while immersed in water, was studied by the Division of Forest Products in the hope of increasing its efficiency and also of finding a more rapid chemical method of achieving the same objective. Promising results obtained with chemical retting on a small scale came too late in the war to have any influence on commercial production.[3] Nevertheless, using the standard but slow method, Australia was able to supply all her own needs of flax fibre and at the same time to export substantial quantities to the United Kingdom.

Carbon for special explosive powders. Charcoal for gunpowders was prepared with great care, since its carbon content and physical state (porosity in particular) exercised considerable influence on the rate at which it burned. The call for special powders for use in fuses for bombs, shells and other military devices caused I.C.I.A.N.Z. to initiate an intensive program of research on the manufacture of charcoal from Australian timbers. This was necessary because charcoal from indigenous timbers was very different in its physical structure from that derived from the

[2] The members were: J. A. W. Stevenson, Dept of Supply (Chairman); W. H. Dolling, Dept of Supply (Finance Member); Dr A. E. V. Richardson, C.S.I.R. (Deputy Chairman); I. H. Boas, CSIR Division of Forest Products; R. B. Hogg, Flax Fibres Pty Ltd, and J. Miller & Co Pty Ltd; and W. F. Weigall, Growers' Representative.

[3] Further work along these lines after the war did not vindicate the earlier promise.

soft woods of Europe which had previously been used for the manufacture of gunpowder. Several thousand tons of special charcoals were successfully produced from local timbers by I.C.I.A.N.Z.

Calcium carbide. The manufacture of calcium carbide, like that of aluminium, necessitated cheap electrical power, and this was one of the reasons for establishing the works at Electrona, Tasmania, where for many years the Commonwealth requirements, together with a surplus for export, had been produced. There was no problem about competition with oversea products since carbide was produced at Electrona more cheaply than anywhere else in the world. Forty per cent of the annual production of 10,000 tons of high-grade calcium carbide was exported. Most of the remainder was consumed in the generation of acetylene for welding.

This favourable position did not long survive the outbreak of war. The Australian Commonwealth Carbide Company Ltd by 1941 was unable to make sufficient calcium carbide to supply the increasing demands of the armed forces and industry for acetylene. This made it essential for the Government to control carbide, acetylene and oxygen. The controls were operated in the first instance by agreement with the sole producers.[4] The shortage, which was only temporary, was due mainly to the large demands of Broken Hill Proprietary Ltd for calcium carbide, where it was required for the manufacture of magnesium, and was relieved when that company produced its own.

Towards the end of the war the Australian Commonwealth Carbide Company was able to supply about 3,000 tons of calcium carbide to the works of I.C.I.A.N.Z. at Botany, New South Wales, for use in the manufacture of chlorinated solvents and polyvinyl chloride, a plastic insulator then coming into vogue in the electrical and radio industries because of its immunity to the effects of high relative humidity. This was the only instance in Australia of the new trend, more marked in Germany than in any other country, towards using acetylene as a raw material in chemical industry.

The Commonwealth Carbide Company found no difficulty in adapting its electric arc furnaces to the manufacture of calcium silicide, a substance closely related to calcium carbide. In the form of an extremely fine powder, calcium silicide mixed with hexachloroethane was used by the navy as a most effective smoke-producing agent.

Phosphorus. Owing partly to the failure of tartaric acid supplies that followed the fall of France, and partly to a threatened shortage of red phosphorus in the match industry, Albright and Wilson Ltd of England (the first firm in the world to make phosphorus on a commercial scale), working in conjunction with I.C.I.A.N.Z., decided to install an electric furnace for making phosphorus at Yarraville (Victoria). Elementary phosphorus, extracted from imported rock phosphate, found three principal

[4] Commonwealth Industrial Gases Ltd made the oxygen and acetylene.

uses: some was converted to phosphoric acid and thence to various sodium phosphates for use either as detergents (sodium hexametaphosphate) or to replace cream of tartar in baking powders (sodium pyrophosphate);[5] some, in the form of red phosphorus, went to the match industry and to the explosives industry for pyrotechnics; the remainder was used in making calcium phosphide. The last substance exhibits the property of bursting spontaneously into flame when thrown on water. For this reason it was extensively used as an ingredient in flares for life-saving rafts.

Potash. Inorganic fertilisers used in agriculture generally contained one or more of the three elements nitrogen, phosphorus and potassium. For the last of these Australia was, until late in the war, entirely dependent on outside supplies. During the first world war, when Germany had a virtual monopoly of potash supplies, the rest of the world went extremely short; but with the discovery in the twenties of extensive potash deposits in the United States and with the growth of an industry in Palestine on the shores of the Dead Sea, this monopoly disappeared. Long before there seemed any likelihood that Australian agriculture might be deprived of this valuable fertiliser, the State Government of Western Australia approached Professor Bayliss[6] of the Department of Chemistry in the University of Western Australia to inquire whether he would collaborate with the Division of Industrial Chemistry in investigating the problem of extracting potash from the extensive and easily mined deposits of alunite (essentially a basic, double sulphate of aluminium and potassium) at Chandler, about 200 miles north-east of Perth. The existence of this large deposit had been known for a number of years and had been thoroughly examined and sampled by the State Government Analyst, Mr Bowley.[7] A team of chemists from the Division of Industrial Chemistry under Bayliss's leadership[8] began work in 1940, and by the end of the year conditions under which alunite must be roasted in order to free potassium sulphate had been sufficiently well defined by means of pilot experiments to permit translation of this part of the process to the commercial scale.[9]

The next stage—leaching out the potassium sulphate from the residue—though thoroughly tested on the laboratory scale, was not, owing to the pressure of time, put through the pilot plant stage. Before this could be done the industry was taken over by the West Australian Government and large-scale operations were undertaken. Two of the most difficult problems

[5] This seeming round-about way of converting calcium phosphate to sodium phosphate was necessitated by the fact that rock phosphates usually contain far more fluorine than can be tolerated in preparations to be used in foodstuffs. By extracting elementary phosphorus this deleterious fluorine was removed.

[6] N. S. Bayliss, BSc, BA, PhD. Senior Lect in Chemistry, Univ of Melb, 1933-37; Prof of Chemistry, Univ of WA, since 1938. B. Brisbane, 19 Dec 1906.

[7] H. Bowley, Govt Mineralogist and Analyst, WA, to 1947.

[8] The members of the team were: R. W. Pickering, W. E. Ewers and G. H. Payne.

[9] The true chemical constitution of alunite was unknown. It was given the conventional formula: $K_2O.3Al_2O_3.4SO_3.6H_2O$. The residue after calcination at 700 to 800 degrees centigrade could be represented by the formula $K_2SO_4.3Al_2O_3$.

which had to be solved were the transport of fuel and the provision of adequate water for the process. The water problem was solved by laying a 4-inch pipeline and connecting it to the main Kalgoorlie pipeline. Owing to the high cost of transport coal was out of the question as fuel, and recourse was made to the use of wood as at Kalgoorlie. Aerial photographs seemed to indicate that ample wood supplies might be found within 10 miles of the plant, but when it came to the point suitable timber was found to be so sparse that within a very short time wood was being carted over distances of 20 to 30 miles. These factors inflated the cost of the project. The alternative proposal considered was to send the raw alunite to Perth and treat it with Collie coal. This was dismissed because of the high cost of transporting a raw material which contained such a low percentage of the final product.

The yield of the water-soluble potash in the large-scale plant (50 to 60 per cent of the theoretical) was substantially lower than had been achieved on the pilot scale (70 per cent). Nevertheless by 1944 the plant was producing potassium sulphate at the rate of 1,000 tons a year. While this was only a small part of Australian requirements, it seemed a promising beginning. Despite all its handicaps the plant's output increased over the next few years, reaching a maximum of 3,696 tons in 1946, and for a time it came within sight of being able to compete with imported potash only to succumb from the rapid rise in Australian wage costs. Thus ended the most promising attempt so far to free Australia from dependence on imported potash.[1] The smaller-scale recovery of potash from the flue dusts of cement kilns in Victoria, which contributed its mite to wartime needs, also ceased after the war.

No serious attempt was ever made to recover potash as a by-product of wool scouring; the possibility of doing so was considered by the Industrial Chemicals Committee, which came to the conclusion that wool scouring was carried out in far too many small plants to make recovery of potash worth while.[2]

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[1] During the period from late 1942 until the end of the war, a good deal of effort was put into the development of a hydrochloric acid process for the extraction of alumina from alunite residues. At the time there was much more Commonwealth interest in this project than in potash production. Once again the large-scale laboratory tests were quite promising and a fairly large pilot had just been completed when the war ended and the project was abandoned.

[2] For a more detailed discussion on this topic see the Symposium on Potassium held by the Royal Society of New South Wales on 7 Aug 1940.

CHAPTER 7

STANDARDS AND STANDARDISATION

RECOGNITION of the importance of accurate measurements in industry has often been associated in the past with the needs of defence, and has in varying degrees been responsible for the setting up of national organisations designed to maintain standards of measurement. Not long after the Franco-Prussian War, the German Government established the Physikalisch-Technische-Reichsanstalt with the object among other things of providing all those industries requiring them with standards of length and other physical quantities. At the turn of the century the Royal Society of London set up the National Physical Laboratory in an old country house at Teddington. Among its earliest tasks were investigations of problems arising out of the supply of munitions during the South African War, when difficulties arose from failure to secure interchangeability of shell fuses.

On the outbreak of the first world war the National Physical Laboratory was able to meet the calls made on it by industry to an extent unequalled by any other organisation or institution in Britain. In 1917 it was taken over by the Government and placed under the Department of Scientific and Industrial Research. It was no coincidence that the American Government set up the National Bureau of Standards in Washington about the time of the Spanish-American War. The threat of a second world war had its share in hastening the establishment of Australia's National Standards Laboratory, though the first attempts to set it up had been made as early as 1912. Though empowered under the Constitution to do so, the Commonwealth Government did not at the time of Federation introduce legislation dealing with weights and measures. The result was that each State continued to have its own laws relating to weights and measures, all substantially the same since they were based on the British *Board of Trade Act* of 1870, but quite inadequate for modern engineering industry. For example the most accurate commercial yard was required to be not more than 0.03 inch longer than and not more than 0.015 inch shorter than the Imperial Standard Yard. None of the Departments of Weights and Measures was equipped for making measurements of the precision required for mass production of munitions.

Valuable pioneer work in educating industry to see the importance of standards had been done by the Standards Association of Australia, whose formation has already been discussed in some detail. The nucleus from which these ideas could be implemented was contained in the Metrology Section of the Munitions Supply Laboratories. In organising this section Leighton had been fortunate in securing the services of Mr. Esserman,[1] who had, while on duty in England during the 1914-18 war, been given the

[1] N. A. Esserman, BSc. Physicist Munitions Supply Labs 1920-38, Assistant Superintendent 1938; Chief, Division of Metrology, CSIR, since 1939. B. Sydney, 24 Jul 1896.

opportunity of studying at the National Physical Laboratory those aspects of war production associated with metrology. On his way back to Australia to take charge of the section he spent some time on similar studies at the National Bureau of Standards in Washington. During the next few years the section was well equipped with precision instruments and provided with a staff trained to calibrate the gauges essential for replicating components of small arms, guns and their ammunition. The section was intended to serve primarily the government factories and firms under contract to them. If, in time of war, a large part of commercial industry was to be engaged in the mass production of munitions, as envisaged in the general plan of defence, it would be necessary to have facilities for calibrating gauges in terms of a common standard of length in all important industrial centres in the Commonwealth.

Consideration of the requirements of defence was, however, not the only motive that inspired endeavours to obtain uniform standards throughout Australia. The strongest motive was the need for standards in the industrial development of the country. The desire on the part of a few scientists to have reliable standards for their researches was perhaps of secondary importance, though it was the earliest of the three motives to manifest itself. The first public advocate of a national standards institution appears to have been Professor Madsen,[2] who felt the need for such an organisation in his own field of electrical engineering.[3] The only way of checking electrical resistance boxes that no longer agreed with one another was to send them back to England, and in the days before commercial air services this involved long delays.

In spite of Madsen's continued advocacy of an Australian national standards laboratory, many years elapsed before there was any promise of its realisation. The prospects seemed favourable in 1926 when, as Madsen was about to leave on a visit to Europe, he was asked by the Chairman of the newly-formed Council for Scientific and Industrial Research (Mr George Julius) to visit the National Physical Laboratory and also the American National Bureau of Standards, to find out exactly what would be required in the way of equipment, accommodation and organisation in setting up a standards laboratory. Madsen brought back with him full details, extending even to a rough draft furnished by the British Board of Trade of the legislation that would be required for proclaiming national standards. When the Committee on the Maintenance of Standards set up with the approval of the Executive Council of the C.S.I.R. made its report and recommendations in 1928, it did so largely on the basis of the information Madsen had collected. Although the scheme put forward by the committee and referred to the Commonwealth Government was based on the far too modest outlay of £10,000, the proposal died. Industry was not yet ripe for it, and even if it had been,

[2] Sir John Madsen, BE, DSc. (Major, Offr i/c Engr Officers' Training School, 1915-19.) Prof of Electrical Engineering, Univ of Sydney, 1920-48; Chairman Radio Research Board since 1927. B. Lochinvar, NSW, 24 Mar 1879.

[3] J. P. V. Madsen, "Australian Standards", *Proceedings of the Institution of Engineers of Aust*, Vol. 9 (1928), p. 91.

the economic depression of the early thirties would no doubt have seriously jeopardised its early life.

With the return of economic prosperity proposals for a national standards laboratory were revived by the Secondary Industries Testing and Research Committee.

> As any engineer of experience may testify (said the committee in presenting its case) the position in Australia is simply chaotic, not because of any lack of efficiency on the part of the Australian manufacturer, but because he is not afforded the gauging and calibration facilities which can only be given by those in authority. There can be no assurance under the present conditions that components made in different factories will fit together with precision, because the master gauges in those factories are *not calibrated at a common source* and therefore do not agree with one another.[4]

The committee emphasised the importance of this disability in defence preparations by a reminder that one of the reasons why Australian engineering industry could not undertake large-scale manufacture of munitions at the outbreak of the first world war was that it did not have the means of measuring with sufficient accuracy to ensure interchangeability of components made in different factories. Events were to prove that in the second world war guns, small arms, ammunition, aircraft, tanks and torpedoes would have to be made not in a few large centres but in hundreds of factories in every State of the Commonwealth.

The Secondary Industries Testing and Research Committee, having before it the work of the earlier Committee on the Maintenance of Standards and the results of its own painstaking investigations, and aware of the plans then being discussed for the manufacture of internal combustion engines for automobiles and aircraft, unhesitatingly recommended the establishment of a national standards laboratory as a matter of the greatest urgency.[5] In this way, the committee believed, the Government could make a most useful contribution to the development of Australian secondary industry.

> The importance of establishing standards as a basic feature for the sound building up of our industries (it declared) permits of no half measure. The Australian standards representing a final court of appeal in matters of measurement in the Commonwealth must be of the highest quality and accuracy, since anything less than this would be valueless. Even these could not be of value to industry unless supplemented by the full range of sub, working and industrial standards through which the process of calibration is brought down to the routine requirements of production. The situation demands that the problem be dealt with comprehensively and adequately.[6]

In their detailed report the committee gave careful consideration to the probable cost, estimated to be about £80,000 for the building and £10,000 per annum for operating costs—much nearer to reality than the

[4] From the Report of the Secondary Industries Testing and Research Cttee (1937), p. 9.

[5] Other recommendations made by the committee, such as the establishment of an aircraft and engine testing and research laboratory (which led later to the setting up of the Div of Aeronautics, CSIR), a division of industrial chemistry, and an information service, will be dealt with in later chapters.

[6] Report, p. 12.

estimates of the earlier committee. No time was wasted in further argument. The Government agreed to establish a national standards laboratory under the control of the Council for Scientific and Industrial Research. Fittingly enough Madsen, who for so many years had worked untiringly to bring such a laboratory into being, was made chairman of a committee to advise the council on planning, erecting, equipping and operating the new laboratory.[7] The committee, the majority of whose members lived outside New South Wales, seldom met, but by dint of consulting his colleagues by telephone and by letter Madsen was able, in between his duties as Professor of Electrical Engineering and Chairman of the Radio Research Board, to guide the fortunes of the new laboratory in its infancy. Esserman, as the only man in Australia with the knowledge and training needed in establishing and running a metrological centre, left the Munitions Supply Laboratories to take charge of the new laboratory, in particular of the Metrology Section; Dr Briggs[8] was appointed Officer-in-Charge of the Physics Section and Dr Myers[9] of the Electrotechnology Section.

Plans for the building had been drawn up in consultation with authorities of the National Physical Laboratory of Great Britain, and on a site made available by the University of Sydney, excavation for the building was begun on the eve of the outbreak of war. While the building was being erected the three section heads, together with six other officers, were sent overseas to gain experience in the special fields in which their interests lay. Maintenance of a standard implied a great deal more than mere care and custody. It entailed a ceaseless search for any alteration in the material of the reference standards, a search for materials of greater permanence and stability for use as standards, and the development of equipment and methods for increased accuracy in comparing the standards with the measures used in commerce and industry. The staff of the National Physical Laboratory gave much help to the visiting Australians on matters of equipment and the general facilities that would be required in the new laboratories.

Though the building was complete and occupied in September 1940, the National Standards Laboratory did not, owing to the war, immediately attain the full status of a national standards institution. Acquisition of much of the equipment considered necessary for this purpose and the enactment of Commonwealth legal standards were deferred until a more appropriate time. Money originally intended for the purchase of basic national standards was diverted to equipment more immediately useful for solving problems likely to arise from the war.

The result of establishing the National Standards Laboratory under these conditions was to provide the munitions annexes and commercial

[7] Members of the committee were: Prof J. P. V. Madsen (Chairman), Prof O. U. Vonwiller (Dept of Physics, Univ of Syd), N. K. S. Brodribb (Contr-Gen of Munitions and Supply), F. J. Shea (Dept of Supply and Development), G. Lightfoot (CSIR), and F. G. Nicholls (CSIR), Secretary.

[8] G. H. Briggs, PhD, DSc. Assistant Prof of Physics, Univ of Sydney, 1928-38; Chief, CSIR Division of Physics, since 1938. B. Concord, NSW, 23 Mar 1893.

[9] D. M. Myers, DScEng. Research Fellow in Elec Engineering, Univ of Sydney, 1937-38; Chief, CSIR Division of Electrotechnology, 1938-49; Prof of Elec Engineering, Univ of Sydney, since 1949. B. Sydney, 5 Jun 1911.



(*Australian Aluminium*)

Heat treatment furnace.



(*Australian Paper Manufacturers*)

A few of the wide range of paper and paperboard products used for war purposes, many of them made from waste paper.

industry of New South Wales and Queensland with services similar to those provided to Victoria and South Australia by the Munitions Supply Laboratories. With its rapidly growing staff of physicists and engineers trained in making accurate measurements of all kinds, the National Standards Laboratory became in effect a second vital centre for the diffusion of these techniques to industry. That it was not able immediately to set up a series of national standards and to secure the passage of the legislation necessary for proclaiming them was, as far as wartime industry was concerned, of little moment. What did matter was that it was able to share with the Munitions Supply Laboratories a burden that might otherwise have been insupportable. The Metrology Section at Maribyrnong had, it is true, been expanded in anticipation of the greatly increased activities that would be necessary to assist industry in the event of war, but these extensions, completed early in 1940, were insufficient to cope with all the work at the height of the great drive for munitions.

The metrology sections of the Munitions Supply Laboratories and the National Standards Laboratory helped industry in a number of ways: by acting as staff training centres, by giving advice on the specification, design and manufacture of working gauges, and by checking the accuracy of gauges when made. At the peak period (October 1941 to September 1942) the Munitions Supply Laboratories checked over 100,000 gauges; for the whole of the war the total was 316,460, of which 100,000 were inspection gauges for the Services, 150,000 were working gauges for annexes, and the remainder were working gauges for aircraft production and other purposes. All gauges manufactured in New South Wales were examined and distributed by the National Standards Laboratory, which also calibrated the measuring machines used by the gauge-making industry.

As the war progressed the demands made on the two main metrological laboratories became so great that some testing had to be delegated to other centres. Much of it was done in workshops of the South Australian Railways, the steelworks of the Broken Hill Pty Company Ltd (Newcastle), Generals Motors-Holden's (Woodville, South Australia), and the Sutton Tool and Gauge Manufacturing Company (Melbourne). Decentralisation of gauge testing greatly speeded up the work.

An organisation undertaking the control of standards of length required:

1. A reference standard[1]
2. Working standards
3. Industrial standards
4. Inspection gauges
5. Working gauges.

The reference standard determined in terms of the Imperial Standard Yard was, on rare occasions, compared with working standards, which in turn were used for the comparison of industrial standards. Industrial standards were used for the control of the inspection and working gauges

[1] Neither the reference standard at Maribyrnong nor the one later held at the National Standards Laboratory constituted an Australian National Standard, but each was known in terms of the Imperial Standard Yard to within 1 part in 1,000,000.

employed in industry. Working gauges, being in constant use, were subject to wear and had therefore to be periodically checked against an inspection gauge which because of its higher quality, less frequent and more careful handling, retained its accuracy for a longer time. Since all the standards were determined in a direct sequence from the Imperial Standard Yard, strict interchangeability of components from all parts of the British Commonwealth was possible. This condition was assured for Australia by having the reference standard at the Munitions Supply Laboratories, and later at the National Standards Laboratory, certified by the National Physical Laboratory at Teddington.

Before 1939 the manufacture of gauges by Australian commercial industry was practically unknown. Consequently when the great drive for munitions began, factories capable of making the many thousands of different types of gauges essential to mass production had to be organised at short notice. Responsibility for the general direction and coordination of manufacture fell on the Directorate of Machine Tools and Gauges, an organisation whose activities will be described at greater length in the next chapter. The Munitions Supply Laboratories and National Standards Laboratory made the unusual gauges that were, as a rule, not required in great numbers. The greater part of the large-scale manufacture of gauges was shared between government instrumentalities, mainly State railway departments, and firms such as the Sutton Tool and Gauge Company, General Motors-Holden's and many others.[2]

Of the kinds of gauges required in large numbers, the screw plug and screw ring caused most concern owing to the extreme shortage of thread-grinding machines. Even though the number of thread-grinding machines increased from 12 before the war to 80 in 1944, it was impossible to cope fully with demands for this type of work. Shortage of thread-grinding capacity was, however, not peculiar to Australia; it was acute also in Britain and the United States.

From a technical point of view probably the most interesting among the special gauges made in this country for the first time during the war were the "slip gauges" made at the National Standards Laboratory. These were pieces of steel in the shape of a rectangular solid of which two surfaces were flat and parallel to within five to ten millionths of an inch and whose distance apart was known to about the same degree of accuracy. They were the most accurate of all precision gauges and could be adopted as either working standards or inspection gauges, according to the quality of the gauges and the frequency of their use. The metal surfaces were so nearly perfectly flat that when one piece of metal was placed in contact with another they adhered strongly and could only be broken apart by a sliding, or slipping, motion. This method of combining gauges by using their adhesive tendency was known as "wringing" and the thickness of any lubricant film existing between the two surfaces was small enough

[2] Other firms were: Stanger and Co Ltd (West Preston, Vic); Rodd (Aust) Ltd (St Kilda, Vic); Cooper Engineering Co Pty Ltd (Mascot, NSW); Automatic Totalisators Ltd (Sydney); Warren and Brown Pty Ltd (Footscray, Vic); Litchfield Engineering Co. (Adelaide); Patience and Nicholson (Melbourne).

to be neglected when reckoning the distance between the outer surfaces of two or more pieces of metal. The conditions necessary for wringing to take place were: (*a*) the surfaces must be flat to within .000010 inch or less; (*b*) surface finish should be of high quality; (*c*) no raised metal or burrs should occur anywhere on the surface.

Slip gauges were made up in sets so that any desired length within particular upper and lower limits could be produced by an appropriate combination of gauges. One of the sets in common use as a precision standard for toolroom production or inspection contained forty-nine pieces, whose dimensions were so chosen that any length from 0.3 inch to 12 inches in steps of 0.0001 inch could be built up, the distance being that of the opposite extreme faces of the set.

Slip gauges were first made by the Swedish engineer Johansson by a process not divulged except incompletely through a patent (the English patent was taken out in 1901) until about 1930 when the secret was sold to Henry Ford, the car manufacturer. The first set of slip gauges reached England in 1908 but it was not until the first world war that their great usefulness in precision engineering was fully appreciated. Steps were taken at the National Physical Laboratory and at the National Bureau of Standards to devise methods for making the gauges, and two different processes were developed independently.

Owing to the great demands for slip gauges in the early part of the war, Great Britain and the United States were unable to supply Australia's needs. The only way out of this difficulty was to make them locally. Late in 1940 Esserman, then Officer in Charge of the National Standards Laboratory, agreed to have twenty-five sets of slip gauges made for the Department of Munitions. There being no staff capable of undertaking the work, Esserman's first job was to train someone. Among the applicants for positions in the laboratory was a plant pathologist, Mr Greenham,[3] from the Division of Plant Industry. Plant pathology seemed an unlikely training ground for a maker of slip gauges, yet Greenham displayed considerable aptitude for the work and was later successful in introducing a number of important innovations in making and using gauges. The secret of his success lay not so much in his professional training as in his hobby of grinding telescope mirrors, an operation requiring infinite patience and skill of a kind most useful in making gauges.

It was obvious that to supply the large numbers of gauges that had been ordered a large staff of workers would be required, and for this purpose it was decided to recruit young women. The Metrology Section was fortunate in obtaining as supervisor Miss B. Paine,[4] a former district commissioner of the Girl Guide movement in New South Wales, who with great tact and skill built up a well-disciplined and enthusiastic team consisting, at first, entirely of Girl Guides, none of whom had ever seen

[3] C. G. Greenham, MSc. Research Officer, Division of Plant Industry, CSIR, since 1945. Plant physiologist; of Canberra; b. Brisbane, 20 Jul 1910.

[4] Mrs R. Stuart. District Commissioner for Girl Guides, Manly, 1939-42; Supervisor Metrology Section CSIR 1940-44; National Emergency Service Ambulance Driver 1939-45. Of Sydney; b. Windsor, NSW.

a slip gauge before. In spite of numerous technical troubles in the early stages of the work, the girls became highly proficient in the art of making slip gauges. At first much of the finishing work on the slabs of stabilised high-quality steel was done entirely by hand, but as experience was gained and the orders for gauges increased, novel machine methods were introduced. With machines it was possible after some trials to make gauges with a surface finish equal to that of the best English hand-made gauges.

A number of new types—half-sized, stepped and tapered slip gauges—permitting a wider range of uses was devised. Work on taper gauges was begun at the National Standards Laboratory before similar gauges were made, by an undivulged process, in the United States. Perhaps the most notable and ingenious of the innovations introduced by Greenham was the saw-tooth gauge used for checking the accuracy of screws.[5]

Altogether 200 complete sets of gauges, calibrated in terms of the Imperial Standard Yard, together with an equal number of specially hard protective gauges (to minimise wear) were supplied by the National Standards Laboratory to different industrial concerns. The production of slip gauges, more especially the very fine ones down to one hundredth of an inch (about the thickness of a safety razor blade), represented a high order of technical achievement and did much to set the standards of length throughout precision engineering industry. As a compliment to Mr Essington Lewis the locally-made gauges were known as "E.L." gauges.

Other outstanding achievements of the National Standards Laboratory were the construction of 40 pitch measuring machines, 200 workshop projectors, 38 bench micrometers, and a gear and hob testing machine.

For the most part gauges were used manually when testing components, but this was too slow for some kinds of manufacture and the tendency, as in other parts of the world, was to make the gauging an automatic process where practicable. In Britain during the first world war machine gauging was applied to the .303 brass cartridge, and at the conclusion of the war one such gauging machine was brought to Australia by Professor Barraclough. For years this machine had lain idle in the Department of Mechanical Engineering at the University of Sydney, but some time after the outbreak of war it was sent down to the Ammunition Factory at Footscray where it once more gave good service.

The principle of air gauging afforded another convenient method of speeding up the gauging process; in this method the clearance between a known gauge and an unknown component was determined by the rate at which air would flow between them. Air gauging not only reduced the amount of skill required for the operation of gauging, it also reduced wear on the gauge. General Motors-Holden's, using pressures up to 30 pounds per square inch, extended the principle of air gauging to new uses and new degrees of precision, claiming that it was adaptable to the detection, when applied to the checking of slip gauges, of differences of as little as three millionths of an inch. "So well was this development received

[5] C. G. Greenham, "Slip Gauges: Their Manufacture in Australia and Some New Types Devised During the War". *Discovery*, Vol. 8 (1947), p. 216.

that a special stand [illustrating their method] was shown by the British Ministry of Supply at an exhibition held in London in August 1943."[6] This principle was developed by the National Physical Laboratory and incorporated in an air-gauging machine which made it possible to gauge all the elements of a cartridge case simultaneously.

Many chemical and metallurgical processes were carried out at high temperatures, and it was often important, if maximum efficiency was to be attained, that the temperatures should be accurately known and controlled. The temperatures most suited to different industrial processes were determined either by factory experience or in research laboratories. Only by close attention to detail could these temperatures be accurately reproduced. The importance of temperature control may be illustrated by an example taken from the metal industry. In order to develop the maximum strength and hardness of an aluminium alloy, such as duralumin, it was necessary to subject it to heat treatment, a process in which the alloy was heated to a predetermined temperature fixed within 5 degrees of 500 degrees centigrade, then quenched and allowed to stand for some days. A whole batch of the alloy material could be spoiled by some quite small departure from the temperature schedule set out for its age-hardening. In the early part of the war many firms were unable to control with any exactitude the temperatures required in processes of this kind.

Fortunately the Munitions Supply Laboratories had, since 1936, taken an active interest in industrial pyrometry. In the Ordnance Factory, where heat treatment for the hardening, strengthening and toughening of steels was an integral part of gun making, control and measurement of temperatures was effected by means of pyrometers calibrated and installed under the supervision of the Munitions Supply Laboratories. These facilities were extended to all government munitions factories, so that by 1939 the laboratories had gained considerable experience in the accurate measurement of high temperatures. Very little had been done along these lines in commercial industry, and when it first turned to making munitions there was a great dearth of instruments capable of accurately measuring relatively high temperatures. Efforts by local firms to make these instruments did not meet with much success and it was not until an annexe was built (near Melbourne) to make pyrometers under licence to the Cambridge Instrument Company of England that the shortage was overcome. The need for the facilities existing at the Munitions Supply Laboratories for standardising temperatures was first felt acutely by industries in Victoria but soon extended to other States and on a scale that necessitated decentralising the work. With help from the Maribyrnong laboratories, industrial pyrometry centres were formed in the departments of physics of the Universities of Adelaide and Western Australia and in the Physics Section of the National Standards Laboratory.

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[6] N. A. Esserman, "The National Standards Laboratory", *Proceedings of the Institution of Radio Engineers (Aust)*, Vol. 12 (1951), p. 44.

At the last centre Dr Briggs directed the setting up of the International Temperature Scale—a scale calibrated in terms of the melting or boiling points of a number of pure substances (oxygen, water, sulphur, antimony, silver, gold and platinum). Under accurately defined conditions these melting and boiling points were reproducible in any part of the world. Though the whole scale was not completed until after the war, the range of greatest importance to industry was covered and by 1942 the section became independent of other laboratories in the standardisation of glass thermometers and pyrometers measuring up to 1,000 degrees centigrade.

At regular intervals members of the Physics Section of the National Standards Laboratory, under Mr Harper,[7] inspected industrial furnaces throughout New South Wales to ensure proper installation of pyrometers and the accuracy of their recordings. One common but easily corrected fault in the early days of the war was that many pyrometers were installed in such a way as to indicate the temperature of the furnace lining rather than of the material being treated. Assistance was given to the major steel-making companies in applying a special method devised by the National Physical Laboratory for measuring the temperature of molten steel—a type of measurement that proved to be of great value.

Not all the measurements of interest were in the region of high temperatures. For example, the vacuum freeze-drying of blood serum carried out by the Red Cross Society required accurate control of low temperatures in the region of minus ten degrees centigrade. Guidance in this work was given by the National Standards Laboratory.

Ambient temperatures were also of interest, particularly those of wooden aircraft operating in the hotter regions of Australia. Information about the temperatures in the wings of these aircraft, which reached 80 degrees centigrade at Cairns and as high as 90 at Alice Springs, and also about the moisture content of the wood used in construction, was essential for intelligent design since both temperature and moisture content greatly influenced the strength of timber and glued joints.[8] This work paved the way for investigating the dangerous stresses that might develop in aircraft flown immediately after standing in the sun for hours. Here again the Physics Section was able to provide assistance in making thermocouples suitable for measuring temperature.

A little-known but none the less significant development in which the National Standards Laboratory participated was the beginning of a scientific glassware industry by Australian Consolidated Industries. Manufacture of high-quality glassware for volumetric chemical analysis, which had previously been imported, was firmly established during the war.

Maintenance of the electrical standards of the Commonwealth was the joint responsibility of the Sections of Electrotechnology and Physics of the National Standards Laboratory. The Physics Section maintained the

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[7] A. F. A. Harper, MSc. NSW State Physicist to Hospitals Cancer Research Dept, Univ of Sydney; Research officer, CSIR Division of Physics, since 1940. B. Sydney, 5 Jul 1913.

[8] W. L. Greenhill, "Temperatures and Moisture Content Attained by Wooden Aircraft in Service in Australia". Report 23 of the Aust Council of Aeronautics.

standards of electromotive force and electrical resistance while the Electrotechnology Section was responsible for all other electrical standards as well as for test work involving multiples and sub-multiples of the ohm.

In the first year of the war the only laboratories organised for chemical, mechanical and metrological testing of materials used in the manufacture of munitions were those at the Munitions Supply Laboratories. Every sample of bronze for chemical analysis, every piece of steel for tensile tests, and every gauge to be checked, had to be sent to them. The great waste of time involved can be well imagined. After September 1940 some of the burden—chiefly the checking of gauges and industrial pyrometers—was taken over by the National Standards Laboratory in Sydney.

The amount of testing required for the many new kinds of manufacture introduced by the expanded munitions program of June 1940 and later, was far too great to be handled by these two centres. The process of decentralisation begun with gauge testing and pyrometry was carried to its logical conclusion by extending it to all the main kinds of testing. On the suggestion of Group Captain Harrison,[1] a scheme of test houses was approved by a meeting of representatives of the Munitions Supply Laboratories, the National Standards Laboratory, and the Australian Chemical Institute held at Maribyrnong on 9th July 1940. Scientific and industrial laboratories in different cities were registered for the purpose of conducting limited ranges of tests and calibrations to a specified degree of accuracy decided upon after the inspection of the laboratory by experts from the above organisations and the Inspection Branches of the Services. The scheme had much to recommend it: it permitted a fuller use of the country's scientific and technical manpower, and it greatly speeded up the work of testing because this could usually be carried out near to the point of manufacture. Its success would depend on the degree of confidence felt by manufacturers in the competence of the staffs.

In all 150 test houses were registered. Laboratories of Commonwealth and State Government departments, of universities and technical colleges, and of private firms, undertook work ranging from the mechanical testing of materials, chemical analysis, X-radiography (of aircraft castings) and electrical testing, to the testing of gauges and pyrometers. Naturally enough difficulties were experienced in the early stages of operating the scheme but in the course of ironing them out the work in the laboratories and in the factories themselves greatly improved. On the whole the scheme was most successful.

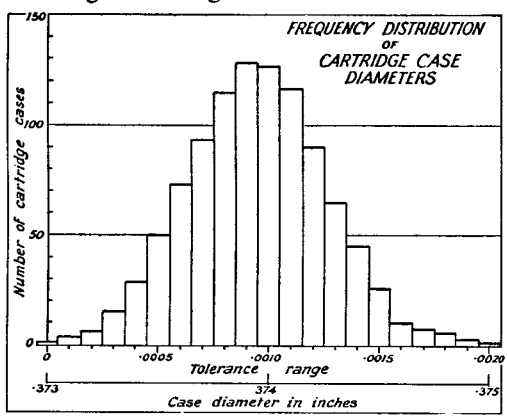
One of the more subtle forms of gauging was that which appraised production processes and the performance of machines engaged in repetition work. The gauge used for this purpose was the technique known as statistical quality control. During the war active steps were taken to widen application of this technique in the United States where in December 1940

[1] Gp Capt E. Harrison. (Served AN & MEF and 1st AIF.) Director of Aeronautical Inspection RAAF, 1928-45. Of Melbourne; b. Castlemaine, Vic, 10 Aug 1886. Died 5 Sep 1945.

the American Standards Association at the request of the War Department began to study the application of statistical methods to the control of the quality of raw materials and manufactured products. Between May 1941 and April 1942 the association issued three American War Standards dealing with the subject. About the same time professional engineering institutions in Great Britain, and the British Standards Institution, began to encourage the use of quality control. In March 1942 the British Standards Institution published a war emergency standard which was essentially a revision of an earlier British Standard published in 1935, and at the same time endorsed the first two of the newly issued American standards.

Following the lead given by the national standardising bodies of Britain and America, the Standards Association of Australia formed representative committees late in 1942 for the purpose of familiarising industry with a technique that promised greater efficiency not only in manufacturing but also in the inspection of finished products. The technique of statistical quality control was by no means a new one, but war provided the great incentive to its wider application.[2] The Department of Munitions, especially its Directorate of Ordnance Production, was quick to grasp the implications of quality control and did a great deal to encourage the propaganda of the Standards Association.

A simple illustration of the technique taken from the manufacture of small-arms ammunition will serve to give a rough idea of how statistical methods were applied to quality control. A cartridge case, for example, was required to have an external diameter lying between the limits of 0.375 inch and 0.373 inch (that is, a tolerance range of 0.002 inch). If when the diameters of, say, 10,000 cartridge cases made during a single run of a well-adjusted automatic machine working to the specified limits were accurately measured, the frequency of the various diameter measurements observed was found to be distributed in a manner conforming closely to the frequency distribution characteristic of purely random or chance variation, the production process was said to be stable in the statistical sense. The frequency distribution of the diameters measured might be as shown in the accompanying figure.

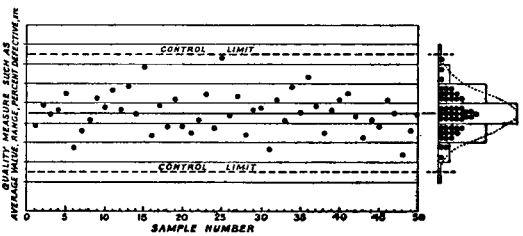


Actually it was not the observed diameters of a large number of cartridge cases, but rather quantities such as average value or dispersion, derived from *small* sub-groups or samples of observed diameters that provided the necessary data for statistical quality control. It was the fact

[2] It was first used in 1924 by Schewhart of the Bell Telephone Labs in the United States.

that such derived values, obtained from a statistically stable production process, had a frequency distribution closely approximating the "normal" one[3] that made possible the practical application of the techniques of quality control to data obtained from samples of a product taken *during manufacturing operations.*

The control chart, as shown in the accompanying figure, provided a simple, direct means by which the degree of variability in the quality measure (for instance, the diameter) was kept under observation during the production process. The horizontal scale represented the time interval between the taking of samples, which were inspected in order of production. Plotted vertically for each sample was the measure of the quality computed from inspection of the sample. These measures of quality might take the form of the average value of the measured diameters of the sample of cartridge cases, or the dispersion (in terms of range or standard deviation) of these measured diameters. The control limits on the chart were placed in positions which were calculated on the basis of previous stable and satisfactory performance.



So long as the machine or process continued to operate satisfactorily, quality measures from the inspection of products sampled at intervals in order of production, when plotted in the control chart, would continue to fall within the control limits, indicating that the variability in the product was inherent in the process, and due to chance causes only. Any departure from this state of affairs was immediately revealed in the control chart and indicated trouble: faulty adjustment of the machine or a worn-out tool, perhaps. One of the great advantages of statistical quality control was that since it was applied during actual production, corrective action could be taken promptly before any serious amount of defective material accumulated. The control chart provided a running commentary as it were on the performances of machines or processes and their operators.[4]

Professional organisations such as the Institution of Engineers, the Australian Chemical Institute and the Institute of Industrial Management provided opportunities for spreading a knowledge of quality control among their members. The subject evoked great interest. A symposium under the general title "The Application of Statistical Methods to the Quality Control of Materials and Manufactured Products"[5] held at the University of Melbourne on 9th December 1942 attracted an attendance of 500.

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[3] That is, the Gaussian distribution observed with large numbers.

[4] A. L. Stewart, "Statistical Quality Control: Theory and Application to Production", *Manufacturing and Management,* Vol. 1 (1946), p. 17; and *Quality Control,* a pamphlet published by the Institute of Industrial Management of Aust (1944).

[5] Papers were presented by Assoc Prof M. H. Belz (Univ of Melbourne), E. A. Cornish (C.S.I.R.) and A. L. Stewart (Standards Association of Aust).

Early in 1943 the Standards Association published Australian Emergency Standards,[6] which were in effect an endorsement of the three American War Standards already referred to. These served as a basis for courses of instruction on elementary principles of statistical quality control given in universities and technical colleges. A meeting of the Standards Association's Quality Control Committee held in Melbourne in January 1943 decided that in view of the potential benefit to war production, the Commonwealth Government should be urged to sponsor the sending of a special mission to the United States to acquire first-hand experience in the application of statistical methods to quality control. Acting on representations made by the C.S.I.R., the Production Executive of the War Cabinet approved the sending of two delegates, one to be nominated by the Department of Munitions, the other by the C.S.I.R.

Between June and November 1943 the two delegates, Mr Moore[7] and Mr Stewart,[8] studied the application of statistical methods to quality control in American industry, particularly in relation to the production and inspection of munitions. Methods used in training men to initiate, supervise and operate the procedures of quality control were also investigated. On their return to Australia, Moore and Stewart made a report in which they emphasised the great advantages that the Service inspection authorities might expect to gain by adopting the techniques of quality control in the acceptance of munitions.

In due course the educational efforts of professional associations and the work of Moore and Stewart bore fruit. Government and private factories began to apply quality control to such diverse operations as spot welding, milling and enamelling of wire, manufacture of small arms and ammunition, and the filling of explosives. In general the new system not only reduced the losses in material, time, labour and productive capacity arising from the manufacture of defective articles, but also exercised a positive influence by improving standards of manufacture.

From a small beginning early in 1944 there was a steady increase in the application of quality control to the problems of inspection, especially in connection with the filling of munition stores with explosive charges. Thus in filling factories it was in many instances possible to replace former 100 per cent inspection—that is, inspection of every item—by systematic sampling based on statistical quality control. The work of sampling, measuring, recording and plotting was undertaken by the staff of the Inspection Division. The resulting control chart, which was in effect a continuous record of the process, was available both to the production staff and to members of the Inspection Division. The former took any action that was thought necessary on the process itself, while the latter

[6] "Guide for Quality Control", "Control Chart Method of Analysing Data", and "Control Chart Method of Controlling Quality during Production".

[7] R. G. Moore, BE. Engineer, Govt Ammunition Factory, Footscray, to 1939, Senior Engineer to 1941, Factory Manager to 1945; Assistant Controller, Machine Tools and Gauges, 1940-41. Of Melbourne; b. Sydney, 7 Nov 1905.

[8] A. L. Stewart, BSc, BE. Asst and later Construction Engineer, B.H.P. Steelworks, Newcastle, 1932-41; Tech Officer, Secretary (Southern Section), 1942-46; Dep Director, Standards Assoc, 1948-53, Dir since 1953. B. Broken Hill, NSW, 13 May 1909.

made up their minds whether the product was acceptable or needed further inspection. In this way quality control forged a new link between production and inspection through the common interest in quality. The link was further strengthened by the appointment of quality-control officers to the production staffs, as was done in a number of government explosives filling factories. Experience indicated that where the responsibility of maintaining control charts fell on the Inspection Division it was not only more satisfactory from the point of view of production and inspection but led to striking overall improvements in quality of production.

Quality control did not absolve or reduce the responsibility of either the production or inspection staff; installation of a control chart did not mean that all worries immediately ceased; it revealed often that the production system was not so efficient as had previously been thought, and occasionally that the effectiveness of earlier inspection was not as great as had been imagined. Had a knowledge of the principles of quality control been gained earlier and applied during the period of peak production of munitions in 1943 the task of the Inspection Division of the Branch of the Master-General of the Ordnance would have been considerably lightened.

Once the pressure of war disappeared, interest in the application of quality control in commercial industry slackened—for a time at least.

The handling of materials—before, during and after manufacture—was an important factor in production costs; 50 tons of materials might be lifted, moved, loaded and unloaded for every ton of the finished product. Expansion of production and the need for greater speed and efficiency brought home to Australian industry the need for giving more attention to this phase of its activities. In order to provide an advisory service, Lewis created within the Department of Munitions a Materials Handling Branch. Coming rather late in the field of industrial engineering, Australia was able to profit considerably by the experience of other countries, particularly that of the United States. An instance of the work done by the branch was the design of a standard tray, 46 inches square, on which materials and components were made up into unit loads at the point of manufacture and moved in this form in and out of store and on to process and assembly lines. Pallets (or trays) of this size were adopted throughout the Commonwealth and replaced the wide variety of sizes that had previously been in use. By promulgating and standardising the principles of handling and packaging, the branch gave valuable help, particularly to government departments and the Services, but also to industry. After the war it became part of the Department of National Development and continued its work in conjunction with the Standards Association of Australia.[9]

Six months before the outbreak of war the Council of the Standards Association of Australia had urged upon the Commonwealth Government the

[9] D. L. Beattie, "Materials Handling and Terminal Arrangement and Operation", *Journal of Institution of Engineers (Aust)*, Vol. 24 (1952), p. 111.

wisdom of preparing a wide range of specifications for defence needs. The association was thereupon given the task of preparing specifications for commodities of interest in the manufacture of munitions. The aircraft industry provided the heaviest program of wartime standardisation. The basis for much of this work was supplied by the British Aircraft Standards (issued by the British Standards Institution) and the Directorate of Technical Development specifications of the Ministry of Aircraft Production (formerly the British Air Ministry).

The number of alloy steels in use in Great Britain and the United States in the aircraft and automobile industries was very large. It would have been quite impossible for Australian industry to manufacture all these alloy steels, and it became the task of the Standards Association, through its appropriate committees under the direction of Professor Greenwood, to select, adapt or originate a limited range of specifications for such steels as were most suited to local requirements and within the ability of the industry to manufacture. Aluminium and other non-ferrous alloys used in the aircraft industry were treated similarly.

When the aircraft industry was obliged to substitute Australian for imported timbers, the Standards Association in collaboration with the Munitions Supply Laboratories, the Division of Forest Products (C.S.I.R.) and the Division of Wood Technology (N.S.W. Forestry Commission), drew up specifications enabling timbers and aircraft plywood from certain indigenous trees to be used in the full assurance that they would serve their purpose as satisfactorily as timbers from Britain or the United States. Since the requirements for aircraft timbers were as exacting as those for alloy steels, it will be evident that the substitution of local for imported timbers had to be carried out with the greatest care.

Codes were prepared for the protection of civilians against possible toxic gases, from enemy bombing, for the rot-proofing of sandbags used in air raid precautions, for packaging of goods, and for many other processes. Many specifications for camouflage paints, based on exhaustive experimental work, were produced. A variety of matters relating to civil defence received attention. Many existing standards had to be reviewed and approved relaxations were allowed in order to permit the use of substitutes for materials which had become unprocurable.

Owing to the shortage of technically trained men, the association experienced considerable difficulty in carrying out all this work. Notwithstanding this disability, over 300 emergency and interim specifications specially designed to meet wartime requirements were prepared.

The work of the Standards Association did not, however, end with the provision of specifications for Australian manufacturers. One of the most important pieces of work it did arose from the fact that Australia was a base for operations in the South-West Pacific Area and so was required to service aircraft and land vehicles of British, American and Australian origin which might on occasion need a minor replacement at any one of a large number of depots. To stock parts for even one make of aircraft was a considerable undertaking, but to do so for many makes was a

very great task. Substitutions of one kind of replacement for another were inevitable. To have allowed depot staffs to make these substitutions on their own initiative would have been to run serious risks, and could not therefore be allowed. The staff of the Standards Association, working long hours, compiled a schedule of standard parts tabulating details of great numbers of items for which spares might be required, with safe equivalents interchangeable in respect of both dimensions and strength. With the help of this schedule, staffs of the repair depots were able to discover for any of the parts listed a number of approved alternatives which might be safely substituted, if necessary. By this simple expedient, the capacity of a depot to repair aircraft at short notice was greatly increased.

Furthermore, the Standards Association had, in the course of its own specifications work, found it necessary to correlate large numbers of oversea and local specifications for the materials from which the spares necessary for the maintenance of service aircraft were made. The association also published a schedule listing specifications of materials and providing a guide to their similarity for substitution purposes. Not long after this schedule had been published in Australia, the Allied nations dealt with a similar problem but on a much larger scale. Those responsible for that project were greatly impressed with the work of the Australian association and made much use of it.

A significant part of the association's war effort was the contribution made by its technical library. Australian industry became standards-conscious to a remarkable degree as a result of the munitions orders with which it had to deal, involving compliance with the large number of specifications, most of which were unfamiliar to industrialists. Their first experience of a new specification was usually a reference to it by some complex classification number. In order to cope with the innumerable inquiries about these, the association's librarian collected and indexed the many series of service and other specifications, and secured copies of most of them for filing. The library soon became recognised, both by Government and by industry, as the information centre on such matters, and a valuable service was thus established.

Another and less tangible benefit resulting from the association's activities was the direct contact established in the course of its work between government officials and industrial executives. The value of these contacts extended beyond the range of actual standards work, and led to better understanding, closer cooperation and the solution of many technical difficulties.

On a still wider scale, the standards bodies in Australia did much, by the exchange of information on research and experience, to strengthen the bonds between scientific and technical institutions in other countries. As a recognition of the service it had rendered in peace and in war, the Standards Association was granted a Royal Charter in 1950.

CHAPTER 8

MACHINE TOOLS

GIVEN manpower, efficient management and adequate supplies of raw materials, the productivity of industry depends to a large extent on the amount and quality of the productive equipment at the disposal of the worker. Machine tools form a major part of the productive equipment of modern industry. They are essential to the basic processes of cutting, forging and casting of metals to which all types of engineering production can, in the last analysis, be reduced. Machine tools have been defined as the machines used to make other machines. They include lathes, forging presses, and machines for planing, drilling, boring, sawing, grinding, milling, filing and reaming. As a matter of convenience the Department of Munitions extended the definition of machine tools beyond the customary limits to cover such things as ball bearings and electrical equipment—furnaces, generators, converters and transformers.

For some years before the war it was evident to defence authorities that the lack of capacity for making machine tools was likely to be one of the most serious obstacles in the way of equipping commercial industry for its part in the munitions program. The position then was that most machine tools used in Australia had to be imported. It is true there were a few firms (such as McPhersons Limited, W. Thornley and Sons Pty Ltd and Nuttall Engineering Pty Ltd) making small numbers of general-purpose machine tools, all of them good enough for the purposes for which they were intended but none of them of the quality essential for the manufacture of munitions. Some of the most notable machines being made in Australia at this time were the high-grade presses and sheet-metal machines of John Heine and Sons Pty Ltd, Sydney, and W. G. Goetz and Sons Ltd, Melbourne. Both firms had been in operation since 1880 and were held in high repute in their particular spheres. There were of course many firms making gears, screws, nuts, bolts and pipe fittings, all of which were indispensable in making munitions. Added to these were highly efficient steel mills and numerous foundries.

That Australia had not made high-grade machine tools on any scale in the pre-war years was to a large extent because there was practically no demand for them outside the government munitions factories. Even if some firm had had the desire to begin this class of manufacture it would have encountered difficulty in finding engineers with the experience to design the machines and tradesmen with the skill needed to make them.

The government factories made a limited number of special-purpose machines; the Small Arms Factory at Lithgow for instance had for a number of years been making high-grade precision milling, surface grinding, drilling and thread-milling machines, but the output was comparatively small—barely more than sufficient to meet its own peacetime needs. None

of the toolrooms of the government factories made lathes: it was far cheaper to import the few that were needed.

The Munitions Supply Board had as its adviser on machine tools Colonel Thorpe, through whom it became aware of some timely moves being made towards the end of 1938 by Australian firms to establish the local manufacture of machine tools. Two competing interests (McPhersons Ltd and E. P. Bevan and Son Pty Ltd) joined forces to secure from a group known as Associated British Machine Tool Makers Ltd the right to make in Australia high-grade machine tools to the British company's proven designs wherever the market should justify it. As a result of these negotiations the two Australian firms amalgamated to form Associated Machine Tools Australia Pty Ltd. The directors of the new company discussed with the Defence Supply Committee how they could best direct the company's activities to assist engineering firms to meet the demands war would be likely to make on them. As a first step they decided to improve the precision of the types of machine tools in current production.

In order to discover what machine tools were already in the country and how they were being used, the Department of Supply and Development issued questionnaires to merchants, manufactures and users of machine tools. The inventory compiled from this information proved of little value when the time came for filling the gaps in supply and for using every machine available for war purposes, but it did show that there were no more than about 40,000 machine tools in Australia and that of these only about 15 per cent were suitable for making munitions. In the first few months of the war it became evident that there was a world shortage of machine tools; Australia was threatened with a delay of twelve months in importing tools for new technical training schemes; equally alarming delays threatened the aircraft construction program. Under pressure of these events the Economic Cabinet on 29th March 1940 approved the formation of a Commonwealth Machine Tools Committee[1] within the Department of Supply and Development, to investigate and report on the requirements of machine tools, and to recommend measures for acquiring them, either from overseas or by promoting their manufacture in Australia.

Lack of money severely restricted the committee's first efforts but when, soon after the formation of the Department of Munitions in June 1940, it was provided with ample funds, the problems of manufacturing machine tools were tackled in earnest and on a scale commensurate with the needs of the new defence program. A Directorate of Machine Tools and Gauges was created within the new department to control the production, reconditioning, acquisition, disposal and distribution of machine tools, ball bearings, electrical equipment, gauges, factory equipment, transmission gears and hand tools. Thorpe, who was recognised by senior members of the government munitions factories and of the Machine Tools Committee as the leading authority on machine tools in Australia, was appointed

[1] The committee was constituted as follows: J. S. Storey (for the Chairman, Aircraft Production Commission); R. H. Doyle (for the Controller-General of Munitions Supply); C. H. McFadyen (for Comptroller-General Dept of Trade and Customs); W. H. Armstrong (for the Premier of NSW); F. H. Harrison (for the Premier of S Aust).

director, with Mr Witten as controller, and given sufficiently wide powers to permit the exercise of the above controls. At first a good deal of reliance was placed on plans for procuring tools from overseas to supplement local manufacture, but as time went on the prospects of importing supplies grew less and less. The successive overrunning of friendly or neutral countries by Germany, and the fact that friendly nations not overrun were preoccupied with their own rearmament programs, all contributed to the difficulties of bridging a widening gap between supply and demand for machine tools in Australia.

In February 1942 the Joint Committee on War Expenditure felt obliged, even though it was outside its terms of reference and few of its members were especially well qualified to discuss this phase of engineering industry, to make a report on what it regarded as a most unsatisfactory position of machine tools. As a consequence of its investigation of munitions production and inspection of factories the committee became deeply concerned about the amount of factory capacity which lay unused because, so it believed, of the shortage of machine tools. It was also worried about the amount of criticism and lack of harmony in the administration of controls and the feeling that existed among manufacturers outside Victoria that their claims for machine tools were not receiving sympathetic treatment by the directorate. This the committee attributed to the fact that the control of the large numbers of machine tools and gauges had been placed in the hands of a single director, though it must have been aware that similar arrangements had been made for all sections of the munitions organisation. The committee was careful to point out that it did not doubt the high qualifications of the director; it did feel, however, that control should be vested in a committee of three members representative of competitive industrial organisations in various States.

In a lengthy memorandum to the Secretary of the Prime Minister's Department on 30th April 1942, Mr Jensen, Secretary of the Department of Munitions, stated that the principal reason for failure to use fully the available factory capacity was the shortage of skilled labour, not of machine tools.

> It is noted (wrote Jensen) that the committee (on War Expenditure) regards the position in respect of machine tools as being "most unsatisfactory", but probably the meaning is that it is insufficient for maximum requirements. That is a position not peculiar to Australia and actually Australia has done extraordinarily well having regard to the small population; probably better relatively than any country in the world. Even the United States with its enormous machine tools industry is 25 per cent below requirements. A comment which might reasonably be advanced is that Australia has undertaken too much in endeavouring to create a munitions industry with practically no resources, at the outbreak of war, in the way of a machine tool industry.

Further, it was extremely doubtful whether a three-member committee would have had any advantage over a single director. An analysis of the directorate's administrative procedure and a statement of the factors governing the allocation of machine tools, seemed to bear this out.

The factors by which the Machine Tools Directorate must be guided are: priority according to rating given by the War Cabinet; priority as between manufacturers employed on the same project; availability of materials to be fabricated on the machine; sequence of manufacturing operations upon components undergoing manufacture in different workshops; date of commencement of a project and set time for completion of a project; manpower; and any other circumstances affecting a decision.

This procedure was explained to the Joint Committee on War Expenditure, but it refused to alter the views it had expressed earlier. Pressure of events, however, enabled the Munitions Department to carry the day.

In the meantime, as overseas supplies of machine tools grew more and more difficult to obtain the conclusion became inescapable that the only way to overcome shortage of supplies was to expand the manufacture of machine tools in Australia. The next two years (1942-43) witnessed an astonishing increase in the number and variety of locally-made machine tools. There was also a great deal of ingenious improvisation in the use of existing machines.[2] Precision tools of a kind whose local manufacture would previously have been regarded as impossible became almost commonplace. At the peak of production in 1943 some 200 manufacturers employed 12,000 persons for an annual output of 14,000 machine tools. By the middle of 1944 what had been Australia's greatest single technological weakness had become a major source of strength. This remarkable transformation owed much of its momentum to the drive and energy of Colonel Thorpe.

Over the whole war period the value of machine tools made in Australia was approximately £23,000,000. Australia's own needs were met and orders were delivered to the British Army in Egypt, to South Africa, New Zealand and India. From making a few machines of medium size Australian manufacturers attained the position of being able to make precision tools of a size and quality that compared favourably with the best of other nations.

Australia's capacity to produce munitions was greatly strengthened by the manufacture of 1,000 modern capstan, combination turret and other Amta-Ward lathes designed to permit the use of tungsten-carbide cutting tools to their maximum capacity. Equally useful were the world-famous Churchill universal grinding machines, special-purpose presses, the Archdale production miller designed for operating economically on light metals such as brass, aluminium and copper and for light duty on cast iron and steel; and Macson, Nuttall and Qualos all-gear, head lathes of a wide range of sizes.

In order to organise the building of heavy machine tools and manufacturing equipment a Factory Equipment Section was set up in the Machine Tools Directorate. No Australian firms had previously specialised in this kind of work, though the steel industry had gained considerable experience in the course of supplying its own needs for heavy machinery. Mr Merrett,[3]

[2] *War Record of General Motors-Holden's Ltd, 1939-45*, p. 24.

[3] F. T. Merrett. Chief Engineer, Aust Iron and Steel Ltd, from 1923; Chief Technical Assistant to Dir-Gen of Munitions 1940-45; Dir of Small Craft Construction 1943-45; Deputy Chairman Secondary Industries Commssn 1944. B. Auburn, Vic, 13 Nov 1890. Died 1 Mar 1950.

Chief Engineer of Australian Iron and Steel, was given charge of the section and asked to organise engineering firms ordinarily engaged in building rough, heavy plant for the mining and steel industry to produce heavy but high-grade equipment. In a very short time a large number of firms, from Kalgoorlie in Western Australia to Mackay in Queensland, were busy making machine tools to a precision and on a scale that would scarcely have seemed possible a few months earlier.

Forty 1,000-ton power presses, thirty-five 1,500-ton and four 3,000-ton hydraulic presses, rolling mills, bulldozers, excavators, brown coal briquette presses, drop hammers, sheet metal presses and forging presses were among some of the important machines made. Others included a complex shell-forging machine; a lathe of 36-inch centre by 100-foot bed, costing £55,000—the largest ever made in Australia; lathes with 36- and 48-inch centre and 50 feet between. The first of these was completed at the Ipswich Railway Workshops (Queensland) with the aid of ninety firms from nearly every State of the Commonwealth. It weighed 132 tons and required eight large railway trucks to transport it to Victoria.

An equally impressive machine was a planer, 12 feet high by 8 feet by 22 feet, designed by Merrett himself. Twenty-five firms in four different States collaborated to construct it. It was large enough to take the whole bed plate of a cargo ship engine, and capable of doing all the planing—lengthwise and crosswise—in one setting. The horizontal boring machines made, with 7½-inch boring spindle, were as large as those made anywhere else in the world. Some of the above machines were built with remarkable speed. A steam, hydraulic, 2,000-ton forging press weighing 80 tons was built and in operation fourteen weeks after its construction was begun. Eight to twelve months would have been a reasonable period to build this machine in time of peace.

As early as August 1939 a decision was made to build a second small-arms ammunition factory capable of making 100,000,000 rounds of ammunition a year, at Hendon near Adelaide. The main responsibility for building the high-priority, metal-working machinery needed to equip the factory at Hendon and to extend the Small Arms Ammunition Factory at Footscray was placed with John Heine and Son and with W. G. Goetz and Sons, who, together with a number of smaller firms, succeeded in making 750 precision machines of 40 different types (mainly presses) valued at approximately £500,000, in the short time of ten months.

In the middle of 1943 when machinery for the production of food was officially declared to be "munitions" the Director of Machine Tools and Gauges was asked to arrange for the manufacture of additional equipment for food processing and for can-making and can-closing. The existing equipment was hopelessly insufficient for the calls about to be made on it.

There were considerable doubts about the ability of firms in this country to build can-body lines capable of making 300 cans a minute. Nevertheless four firms, Messrs John Heine and Son and J. Jardyne Pty

Ltd of Sydney, and W. G. Goetz, and Smith and Searls of Melbourne, working at great speed succeeded in building between them some 200 machines with a potential output of 1,250,000,000 cans, the estimated Australian annual requirement at the time. This augured well for the future of the food-processing industry. According to one authority it placed Australia abreast of the United States in can-making techniques. Qualifying this achievement, it must be noted, was the fact that Australia could not make her requirements of tinplate. Plans for the installation of plant for this purpose at B.H.P's Port Kembla works had been drawn up just before the war, but had perforce been laid aside.

Equipment for the processing of millions of gallons of tomato and citrus fruit juices and for dehydrating fruits and vegetables, and more than 7,000 electric motors to operate food processing machines, were all made in a short time to help Australia to play her part in feeding the Allied Forces in the South-West Pacific Area. Most of the electric motors made in Australia at this time were small; the largest, built by Australian General Electric, did not exceed 450 horse-power.

In the Beaufort Division of the Department of Aircraft Production a 3,000-ton forming and blanking press was needed for making various struts and framework. As there was no machine in Australia capable of doing this kind of work, one was improvised by using the superstructure of an existing hydraulic press as a working base. This, together with parts made in Queensland, New South Wales and Victoria, was ultimately assembled at General Motors-Holden's works at Woodville, South Australia.

An item of interest supplied to De Havilland Aircraft Pty Ltd was an Australian-built, circulating furnace for the heat treatment and annealing of dural propeller blades. For the forging of propeller blades a 35,000-pound drop hammer, the largest of its kind in Australia, was installed in the heavy forge annexe operated for the Commonwealth Government by the Australian Aluminium Company at Granville. This drop hammer, along with a 5,000-pound roughing hammer and a 500-ton trimming press, was supplied by the United States.

During the period 1919-39 Australian engineering industry had developed the transmission of power by gearing to the stage where it could supply the requirements of the steel, mining, rubber and other heavy industries. It is true that manufacturers were greatly dependent on oversea suppliers for their gear-cutting tools; such gear-making plant as Australian industry then possessed was incapable of sufficient accuracy to make gears for marine or aircraft engines or for precision measuring instruments. The war saw changes in both situations: a diminished dependence on oversea supplies of gear-cutting tools, and a greatly increased importation of high-grade machinery for making the accurate gears needed for range-finders, predictors, recording instruments and radar equipment.

In the early days of the war, before local manufacture of machine tools was firmly established, the only way of meeting Service demands at times was by taking over machines from firms that were considered by the directorate to be using them for non-essential purposes. Owners were naturally reluctant to lose their machines, especially when they represented years of hard work in building up a small business. It is indicative of the spirit of the times that well over 100 machines were so purchased without the need for invoking the National Security Regulations more than once.[4] At the same time quite elaborate work was often farmed out to small three-man or four-man workshops. The scope and extent of this dispersal would be difficult to estimate, but the practice was a sound one: it was for example one of the reasons why German engineering was so hard to damage by air attack.

Although not strictly speaking machine tools, ball and roller (anti-friction) bearings were so generally used in the rotating or oscillating parts of machines that their control and procurement for the munitions program were made the responsibility of the Directorate of Machine Tools and Gauges. Anti-friction bearings were manufactured in some 20,000 different sizes and types, ranging from bearings one-sixteenth of an inch in diameter for fine instrument work to heavy-duty thrust bearings with an external diameter of about 2 feet 6 inches for railway turntables and steel rolling mills. Before the war Australia was entirely dependent on outside supplies of ball and roller bearings, importing them from the United Kingdom, Sweden, the United States, Germany, Italy, France and Czechoslovakia, in that order of importance. Owing to the variation in standards between so many different countries of origin, authorities of the directorate experienced great difficulty in formulating uniform policies of control. These variations caused considerable complications in the replacement of bearings in imported equipment.

Ball and roller bearings were critically short during 1942; a few odd shipments only were obtained from Sweden. Losses of shipments by enemy action were particularly severe during that year and it became imperative to take steps to relieve the position. The process of making ball bearings consisted of forging and machining the steel balls, and of machining on lathes the housings, or grooved rings and shells into which the balls (or rollers) were nested. In the absence of equipment and machinists skilled in making the balls, the earliest attempts at manufacture were restricted to making the housings. Two small firms undertook the production of housings and after considerable trouble and experimentation, especially in regard to the correct heat treatment of the steel specified, they were successful in producing satisfactory housings for assembly with imported steel balls and rollers. Between them they manufactured about 100,000 ball and roller housings of 50 different sizes, for shell-turning

[4] "One of the most heartening examples of cooperation was that of a Dandenong tank maker who, when he was told in the early phase of the Japanese war that his entire plant consisting of four machines was required by the Army forward areas, stated 'Take them', and actually offered to arrange their transport to Melbourne. Needless to say it was with a good deal of pleasure that recently we were able to assist in re-equipping this shop." (C. J. Pawson, "The History of the Directorate of Machine Tools and Gauges", p. 380.)

lathes, 3.7-inch anti-aircraft guns, magnetos (for army engines), equipment for the Beaufort bomber, and many other purposes.

Early in 1942 two engineers of the Government Ordnance Factory, Messrs Brown[5] and McRae,[6] went to the United States to study the technique of making steel balls for bearings. There they were given much assistance by the New Departure Manufacturing Company—a division of the General Motors Corporation. Under the Lend-Lease Agreement permission was obtained to purchase about 50 per cent of the plant required to set up a factory for making ball bearings—the remainder to be supplied by Australia. With this substantial help a modern factory was built at Echuca, Victoria, to produce ball bearings in the sizes most in demand. The Department of Munitions was fortunate in the high quality of the technical assistance it received in establishing the manufacture of a product so vital to engineering.

Among the more important machines for which the Echuca factory began making bearings in June 1944, were:

Gray Marine Diesel Engines: 1,715 sets of bearings
Cheetah Aircraft Engines: 40,000 steel balls
Gravity Conveyor Rollers: 6,000,000 steel balls
Mechanical coal-winning equipment: 29 sets of large thrust bearings.

In war speed of production was vital. From the many factors that made for high production rates two only will be chosen for mention. The first of these, welding or the joining of pieces of metal, usually under heat and pressure,[7] played a vital role in fabrication of ships, aircraft, tanks, armoured vehicles, bridges and many other types of war equipment. Australian engineering industry made use of all the most modern welding techniques. In the building of ships and armoured vehicles, for instance, arc-welding enabled speeds of fabrication that would have seemed impossible in pre-war days. It also made for reduced weight without loss of strength. More than 1,000 arc-welding machines, some of them consuming a current of as much as 1,000 amperes, together with millions of feet of electrodes of a wide range of size and composition, were supplied to industry and the armed forces by the E.M.F. Electric Company Pty Ltd, a subsidiary of Commonwealth Industrial Gases Ltd.

The method of electrical welding known as resistance welding, was also widely applied. In the form known as butt welding it was used to make large anchor and mooring chains, a new development in Australia. Spot and seam welding, which produced an effect similar to a row of rivets, were used for joining sheets of metal, especially where streamlined surfaces were required. Spot welding speeded up operations in the aircraft

[5] J. S. Brown, 1st class Machinist and Foreman, Ordnance Factory Maribyrnong from 1925; acting engineer 1942. B. Lithgow, NSW, 13 May 1896. Died Jul 1947.

[6] A. D. McRae, Machinist, Ordnance Factory Maribyrnong from 1932; acting engineer 1942. B. Berringa, Victoria, 11 Apr 1907.

[7] Some metals will weld even without heat being applied; two pieces of platinum, gold or silver can be joined by hammering provided the contacting surfaces are clean and flat. Two pieces of metal with nearly perfectly flat surfaces (optically flat surfaces) can be welded together at room temperature by the application of relatively small pressure.

industry, where it was used for joining stressed aluminium parts. The Mustang, for example, was an almost entirely spot-welded aircraft.

The suddenness with which contingencies arose during the war led to a more widespread appreciation of the merits of oxy-acetylene welding, though this form of welding did not lend itself to mass production so readily as those already mentioned. For cutting metals under water, as in repairing ships, the oxy-acetylene flame was effective only to a depth of 25 feet. New equipment employing an oxy-hydrogen flame enabled shipping repair work to be carried out at much greater depths.

In order to obtain the most satisfactory results in high-grade machining it was customary to lubricate the cutting tool with a cutting fluid. Early in the war large quantities of cutting fluids, whose exact nature was not known to local manufacturers, were being imported for the aircraft and other industries. A series of laboratory experiments and standardised practical tests organised by the Lubricants and Bearings Section of the C.S.I.R. demonstrated that an indispensable property of a cutting fluid was its ability to lubricate metal surfaces under severe conditions of load and at high temperatures. The ability of a fluid to function in this manner depended on its containing certain substances. Once the nature and mode of action of these substances—high-pressure lubricants—was understood the Lubricants and Bearings Section, in collaboration with the Munitions Supply Laboratories, was able to devise improved cutting fluids that could be produced locally.

High-pressure lubricants used alone proved most useful in another metal-shaping process, namely drawing. This operation, in which a metal was forced through a die, was used in making cartridge cases and wires. Owing to severe friction, high temperatures were developed at rubbing metal surfaces during drawing, and some form of lubrication was essential. In these circumstances the most effective lubricants proved to be organic compounds containing sulphur, chlorine or other active groups capable of combining with metals to form stable metal chloride or sulphide films that greatly reduced, even at high temperatures, the extent of metallic seizure and wear. With this knowledge of the way in which high-pressure lubricants facilitated the drawing process to guide them, the Lubricants and Bearings Section devised new and still-better lubricants.

Turning, drilling and milling of metals were among the most important and basic operations in engineering industry. In making gun barrels from metal forgings by means of these operations, as much as 50 per cent of a forging or casting might have to be machined away. A cutting tool must be harder than the material upon which it is used, and it must retain its cutting edge even when red hot; it must not break under moderate impact and the cutting edge must be capable of being reground after it has become worn. Early in the history of the tungsten filament lamp industry a search was made for a substitute for diamond dies in wire drawing. Tungsten carbide, which is almost as hard as diamond,

appeared to be the most promising material but it was far too brittle for making dies or cutting tools. The remarkable discovery was then made that the carbide could be sintered into a tough mass by compacting it with finely powdered cobalt. When the mixture was heated, the cobalt acted as a cement or bond holding the carbide particles together. In the hands of Krupps, the German armament makers, cemented tungsten carbide was developed not only as a material for making dies for wire drawing but as a wonderfully useful material for the tips of cutting tools. Not long after it was put on the market in 1926 under the trade name "Widia", the General Electric Company of the United States bought the basic patent rights from Krupps. After experiencing some early difficulties in manufacturing details, in the course of which the company is said to have spent approximately 1,000,000 dollars in research, the manufacture of cemented carbides suited to the drawing of tungsten wire was successfully achieved. Foremost among the manufacturers of cemented carbides in the United States was the Carboloy Company (Detroit), a firm that provided one route by which the technique of making cemented carbides later reached Australia.

Cemented tungsten carbide was the best substitute for diamond yet discovered for machine-cutting tools and wire-drawing dies. Its efficacy in drawing wire was soon recognised in Australia. Dies imported from Germany were in use in Rylands' (Newcastle) as early as 1927. Its remarkable superiority even to high-speed, tungsten tool steel for deep cuts is illustrated by the following figures showing a comparison of the rates at which mild steel could be removed on a lathe with the two kinds of tool.[8]

Material of tool	Surface speed in feet per min.	Volume of steel removed in cubic in. per min.
High speed tungsten tool steel	86	13
Cemented carbide	367	54.5

In machining operations the substitution of tungsten carbide for high-speed steel could lead to a fourfold increase in the production rate. Britain, France and the United States were at first relatively slow to adopt the new material and it is estimated that in 1938 Germany had twenty times as much tungsten carbide in use as had the United States.[9]

In Australia the manufacture of cemented tungsten carbide was undertaken independently and about the same time by three different firms. The Broken Hill Proprietary Company with its associated steel-fabricating industries was probably the first to realise the need for making Australia's defence industries independent of outside supplies of this strategic material. Just before the war the B.H.P. began negotiations with oversea firms for information concerning the processes of manufacture, but the negotiations failed. In December 1940 the company began work on its own initiative

[8] From *British Science News*, Vol. 1 (1948), p. 16.

[9] *Fortune*, February 1942.

at the Newcastle steelworks. From a survey of the fairly voluminous literature and numerous patents on the subject of cemented carbides, it was evident that relatively little systematic experimental work had been published and that much of the process of manufacture was still secret. Making what use it could of the published information, the B.H.P. research team succeeded on 15th January 1941 in producing on a laboratory scale the first wire-drawing die, but not until April of that year were they able to make material capable of cutting steel at a high speed. To attain the latter objective the investigators had to discover how to incorporate another carbide, namely titanium carbide, in the matrix. In the absence of titanium carbide a tool tip[1] when used to cut steel at a high speed, gave rise to a defect known as cratering. A pilot plant including a section for making tungsten from King Island scheelite was completed in September 1941, and within about a month the first steel-cutting tips were being produced in quantity. In little more than twelve months after investigations had begun, the B.H.P. annexe was using locally-made tool tips to produce 25-pounder shell bodies.

Starting somewhat later than the B.H.P., Australian General Electric entered into an agreement with Associated Machine Tools Australia Pty Ltd for the formation of a new company to be known as Hard Metals Pty Ltd. An agreement was reached between Australian General Electric and the Carboloy Company whereby an Australian engineer, Mr Rooste,[2] was sent to study the latter's manufacturing process at Detroit. On his return to Australia rapid progress was made with the installation of a plant at Auburn, New South Wales, and in September 1942, nine months after starting, the first batch of tips was made. Hard Metals Pty Ltd relied on B.H.P. for its supply of tungstic oxide, the raw material for making metallic tungsten. The early difficulty of obtaining cobalt metal of sufficiently high purity was solved by the Electrolytic Zinc Company at Risdon, Tasmania, where cobalt was obtained as a by-product of the purification of zinc sulphate solution before its electrolysis.

The grade of steel-cutting cemented carbide made by Hard Metals Pty Ltd differed from that of the B.H.P.; the B.H.P. made the titanium-tungsten type that had been developed in Germany. Tips of this material were not successful when used under the conditions obtaining in American machine shops, which required for efficient operation a material less liable to failure than the titanium-tungsten carbide. After extensive investigations the Carboloy Company devised a material incorporating three carbides—tungsten, titanium and tantalum. Ores of tantalum were extremely rare, but Australia was fortunate in having one of the world's richest deposits of tantalite at Wodgina on the Pilbara goldfields of Western Australia. Several tons of these tantalite ores and some from the Northern Territory

[1] Because of the high cost of the material, only the tip of a cutting tool was made of cemented carbide.

[2] E. E. Rooste. Engineer in charge of inspection; in United States 1941 and 1944 to study manufacture of tungsten carbide products; on loan to Hard Metals Pty Ltd 1942-44; in charge of laboratory Aust Electrical Industries Pty Ltd since 1946. Of Sydney; b. Kaunas, Lithuania, 23 Oct 1896.

were purchased by Hard Metals Pty Ltd, and satisfactory methods for making tantalum carbide were evolved. All the requirements of cemented carbide tool tips for Associated Machine Tools of Australia were met by the Auburn plant. A third firm, the G.B.S. Hard Metals Company at Prahran, Victoria, which in its early developmental work had received the backing of the Department of Munitions, also succeeded, after some initial failures, in making a grade of cemented tungsten-titanium carbide well suited to the needs of the Ordnance Factory at Maribyrnong. The Melbourne firm was unaware of the Sydney work until it discovered that two companies had been registered under substantially the same name.

While the above three companies were developing commercial processes, an intensive academic research program on the carbides of tungsten, tantalum and titanium was being followed by Professor Greenwood and Mr Honeycombe[3] in the Department of Metallurgy, University of Melbourne. As far as can be ascertained, the three commercial firms made no use of the work, but the experience gained in the practice of powder metallurgy, which was the basis of the process for making tungsten carbide, was turned to good account in the setting up of a pilot-scale plant for making tungsten wire for the lamp and valve industry.[4]

When first introduced into Australian engineering industry, tungsten carbide tips, especially in the machining of 25-pounder shell, appear to have been consumed unduly rapidly, partly because of inexperience in their use but mainly because of their poor quality. The Directorate of Technical Practice was asked by the Director-General of Munitions to make an inquiry into the reasons. The marked improvement in the standards of local production towards the end of 1943 caused the inquiry to fizzle out.

Tungsten carbide, originally developed as a substitute for the more expensive diamond, wire-drawing dies, did not entirely displace diamond, which was among other things essential for fabricating tungsten carbide itself—that is for grinding and drilling it. For other purposes, especially for thread cutting and the drawing of the very fine wires used in range finders, gun sights and communication equipment, diamond was the material of choice. Only its cost prevented its wider use.

The industrial diamond tool industry which sprang up in Sydney just before the war was something entirely new to the country. The piercing, polishing and mounting of diamonds for wire-drawing had been a highly specialised art, practised mainly in Holland, Belgium and France. The man mainly responsible for bringing this art to Australia was Mr Jules Joris,[5] a Belgian who, when the first world war broke out, was withdrawn from

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[3] R. W. K. Honeycombe, PhD. Research Scholar in Metallurgy, Univ of Melbourne, 1941-42; Research Officer, CSIR Lubricants and Bearings Section 1942-45; Prof of Physical Metallurgy, Univ of Sheffield, England. B. Melbourne, 2 May 1921.

[4] Powder metallurgy was the technique used to fabricate metals whose melting points were so high as to preclude their being cast. The finely powdered metal was usually compressed in a die of suitable shape and then subjected to heating. Before tungsten could be drawn into wires, blocks or cylinders of the sintered metal had to be submitted to a process of swaging. Details of this highly technical operation were worked out by Prof J. N. Greenwood, in whose department tungsten wire was drawn for the first time in the Commonwealth.

[5] Jules Joris. Cutter of gems and industrial diamonds. Of Sydney; b. Antwerp, Belgium, 27 Feb 1888.

the Belgian Army and asked to supervise the use of industrial diamonds at Kynoch's, in Birmingham, England. After the war he returned to Belgium, where, although mainly concerned with cutting diamonds for the jewellery trade, he retained his interest and activity in their use for industrial purposes. In 1930 Joris came to Australia and began gem cutting in Sydney. About two years before the second world war broke out he was asked by the Tool Equipment Company Pty Ltd whether he could make the special diamond tools for thread-forming on fine abrasive wheels which hitherto had been imported. After he had demonstrated that this highly skilled work could be done locally, word got round to other factories such as Lithgow Small Arms, which began to place orders with Joris for their requirements of industrial diamonds. When war broke out the Department of Supply, realising the importance of this very small industry and that the factory it then occupied would be much too small to handle the probable requirements of the munitions program, arranged for its removal to larger premises. Joris and his son designed and made the numerous machines, projectors and jigs then unprocurable in Australia and began training thirty to forty men and women to operate them.

In this factory diamonds were cut to different shapes and sizes to within an accuracy of 7/10,000ths of an inch to suit British, American, Swiss and German thread-grinding machines. Diamonds for testing the hardness of steels, the abrasiveness and hardness of paints, and diamonds for truing and shaping abrasive wheels, were also prepared. Diamond lathe and boring tools were the most suitable tools for machining many materials—the aluminium alloys used in the automotive and aircraft industry, the bronze and manganese bushes and bakelite nose-pieces of bombs. The same factory also made diamond-impregnated bakelite and metal-bonded wheels for grinding tungsten carbide tips, cocking pieces of rifles, hones impregnated with diamond dust for honing aircraft engine cylinders, .303 rifle and machine-gun barrels, and cylinder liners. Ultimately it succeeded in constructing diamond piercing machines capable of making dies for wires ranging from 0.002 to 0.06 inch diameter within an accuracy of 1/10,000th of an inch.

In 1943 Thorpe wrote:

> There is, generally speaking, no machine too large or too intricate for the Australian engineer to tackle, if the need is sufficiently urgent. . . . There are now available through the cooperation of manufacturers, engineering shops, certain garages, instrument makers, tool making establishments and others, more than 180 organisations producing tools and gauges to the extremely fine tolerances demanded by modern engineering practice and munitions manufacture.[6]

Early in 1944 Sir Oliver Simmonds, M.P., who came to Australia from England to investigate the industrial position, was astonished to find that of 52,000 complex machine tools being used in Australian industry 11,000 came from the United States under Lend Lease, 5,000 from Britain, and

[6] *Australia Today*, 38th issue (1943), p. 37.

37,000 had been made in Australia. That, as he later told the House of Commons, was a staggering figure to have to contemplate, and lent point to an earlier observation he had made concerning the uncertainty of Britain's post-war prospects as an exporter of machinery to Australia. This achievement would have been creditable under the best of conditions. As it was many difficulties stood in the way, the greatest being the shortage of skilled manpower. No project was ever completely blocked for want of machine tools though many were delayed from this cause.[7]

[7] In writing this chapter I have made use of "The History of the Directorate of Machine Tools and Gauges" by C. J. Pawson.

CHAPTER 9

MANPOWER: TECHNICAL AND SCIENTIFIC

FEW factors caused more anxiety to those directing the nation's industrial war effort than the fear that there might not be enough skilled and highly trained men to carry it through. This situation arose, partly at least, because of the inadequacy of the facilities provided by the different States for technical education. Each State had its own system and there was no uniformity in standards, methods or systems of administration. It was not sufficiently widely appreciated in the late thirties that in a war certain to be fought with highly mechanised forces equipped with a wide range of complex technical devices, there would be a great demand for all kinds of trained and skilled men: some to devise and develop scientific equipment and arms, and many to make and more still to use them.

It is impossible to draw a sharp line of demarcation between scientific and technical manpower; a rough distinction may be based on the minimum time needed for training individuals in the two categories. For the purposes of this chapter it will be convenient to group under scientific manpower all those whose whole-time training extended over three or more years: research scientists, including physicists, chemists, geologists, botanists, zoologists and many others; applied scientists or technologists; and the many kinds of engineer (electrical, mechanical, civil) and engineering technologists. The number of individuals in these categories could not be suddenly increased. The principal concern during the war was to see that their numbers were maintained and that they were used where they were most needed and where they could be most effective.

Under the heading of technical manpower will be included all those whose training occupied much shorter periods of time or whose training, spread over a number of years of apprenticeship as in the case of skilled tradesmen, called for practical rather than scholastic qualifications. The problems that arose in relation to technical manpower were more obvious, more urgent, and perhaps easier to handle than those of scientific manpower; certainly they were among the earliest to be grappled with.

After the first world war technical training in the different States was able to keep pace with the needs of a slowly growing secondary industry, until the advent of the economic depression. During those years expenditure on technical and other forms of education shrank considerably. In the years of recovery when, under the influence of the Government's tariff policy, the growth of secondary industry was accelerated, technical education lagged behind. The very policy used to stimulate the expansion of secondary industry reduced the Government's income and therefore tended to reduce the amount of money available for education.

Alarmed at this trend which was perhaps more marked in New South Wales than in any other State, Mr Drummond,[1] Minister for Education in New South Wales, took the initiative at a conference of Ministers and Directors of Education held in Melbourne in 1936 to urge the Commonwealth Government to make a substantial capital grant to the States for a thorough reorganisation and equipment of technical education. This step, he argued, was essential not only for the efficient conduct of industry but also to prevent the wastage of human resources through unemployment, which was still rife. The Commonwealth took no action on this recommendation because, under the Constitution, education was a State responsibility.

On his return late in the same year from a tour of inspection of technical training systems in Europe and North America made soon after the Melbourne conference, Drummond was more than ever convinced of the urgent need for improving the Australian system of technical education. His first-hand experience of the disturbed condition of Europe led him to attach more importance to considerations of defence. Though public opinion was, on the whole, opposed to any suggestion for spending much money on defence, even indirectly, Drummond was able to persuade the New South Wales Cabinet to increase expenditure on technical education from the 1936 figure of £230,943 to £450,376 in 1937. Some of the money earmarked for buildings in 1937 went towards the erection at Newcastle of a large modern technical college, the science block of which, known as the Edgeworth David Building, was opened in 1938. The citizens of Newcastle and local industry, mainly the B.H.P. and its subsidiary companies, created a precedent by contributing approximately £80,000 towards its cost. Though no other State spent so much as New South Wales did on any one project, each State, in the years immediately preceding the war, made some progress towards bringing its system of technical education more up to date. Even so, by 1938 the proportion of the male population undergoing technical training in Australia was little more than half that of the corresponding age group in England and Wales. Drummond could also still affirm, as he did at a conference of the Australian Education Council held in Hobart early in the war, that Australia was lamentably short of teaching staff, equipment and buildings for technical education.

Concern over the necessity for strengthening the system of technical education in the cause of defence was of course shared by authorities in other States, especially in Victoria. From his experience during the first world war Mr Jensen knew that in the event of a second war there would be a strong demand for skilled men both for the munitions industries and the Services themselves, and not long after the Munich Conference he began discussions on technical manpower with Mr Eltham,[2]

[1] Hon D. H. Drummond. MLA NSW 1920-49; MHR since 1949; Minister for Education, NSW, 1927-30, 1932-39. B. Sydney, 11 Feb 1890.

[2] E. P. Eltham, ISO; BEE. 1st President Victorian Apprenticeship Commission, 1928-34; Chief Inspector of Technical Schools and Deputy Director of Education in Vic 1930-46; Director of Industrial Training, Dept of Labour and National Service, since 1940. B. Boolarra, Vic, 15 Sept 1892.

at that time Chief Inspector of Technical Schools for the Victorian Department of Education. Jensen outlined the probable requirements of skilled tradesmen, and on this basis Eltham worked out a scheme for the intensive training of workers. Nothing further was done until after war broke out. On 25th September 1939 interested Commonwealth departments met to survey the facilities available for training. There was considerable difference of opinion as to where the training should be done—whether the State instrumentalities for technical education should be used or whether the Commonwealth should establish its own training centres. This issue was not settled until mid-1940 when the reverses in Europe made it imperative to reach some decision. Representatives of the Commonwealth and the States, of industry and technical education, then met and formulated the Commonwealth Defence Training Scheme which was placed under the administration of the Department of Munitions. Eltham was made Commonwealth Director of Industrial Training; the Superintendent of Technical Education in each State became a deputy director and was responsible for the training in his own State. Each State appointed its own advisory committees consisting of representatives of industry and technical education. Effective liaison between the States was maintained through frequent conferences of deputy directors at which the work of training was reviewed and coordinated.

In developing the scheme, the cost of which was borne by the Commonwealth, use was made by negotiation with the States of the facilities already existing in their technical schools and colleges and the administrative machinery of their education departments. The first objective of the new scheme was to train 2,500 skilled engineering tradesmen, including 500 precision tool and gauge makers, who were in a very real sense key men. Industry was gravely deficient in men capable of working to the high precision essential for making munitions. The technical colleges themselves were at first neither sufficiently well equipped nor properly staffed to give training in high-precision engineering; it was, in fact, necessary to supplement existing staff by bringing out from the United Kingdom instructors to train Australian instructors.

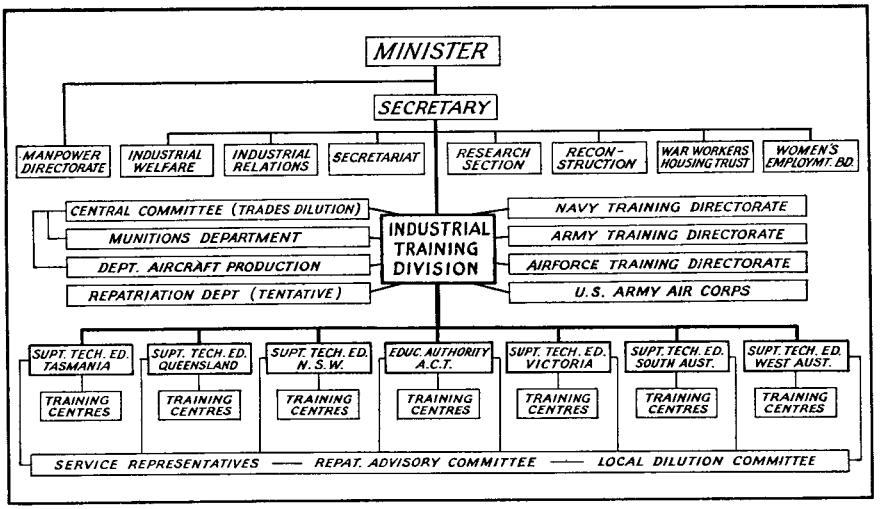
The Commonwealth Government provided additional buildings and workshops, contributing in all some forty such units costing about £250,000, together with machine tools needed for the purpose of instruction. As a first step towards providing the latter, Mr Ellis,[3] Principal of the Melbourne Technical College, visited the United States to select and buy, from a fund of £125,000 allotted by the Commonwealth, precision tool-making and gauge-making equipment. A further sum of £270,000 was authorised in 1940 for similar instructional machine tools and equipment. While all these arrangements were being made there was no shortage of general manpower in Australia, but only of skilled manpower. The introduction of the Empire Air Training Scheme in December 1939 made it

[3] F. Ellis, MA, BE. Principal, Melbourne Technical College, 1927-52; Adviser on Vocational Training to Egyptian Govt 1953-54. B. Adelaide, 24 Feb 1886.

clear that far greater numbers of skilled tradesmen and technicians would be needed for the Services than had at first been estimated.

Under the Commonwealth Technical Training Scheme there were two main categories: men of the armed forces whose training was part of their service; and men who were required by the Munitions Department and the Aircraft Production Branch for work in war production factories. The place of the training scheme in the organisation of the Department of Labour and National Service set up in October 1940 when, as mentioned earlier, the Department of Munitions relinquished its responsibility for technical training, is indicated in the accompanying chart.

Courses for servicemen were begun at the Melbourne Technical College on 18th December 1939, when 100 R.A.A.F. fitters were enrolled. Similar



classes followed quickly in other States, and by April 1940 the number of army and air force trainees had risen to 1,885, of whom 500 had already completed their courses. The following list will convey some idea of the extent and variety of the training carried out for the Services:

Navy

Wireless mechanics, anti-submarine (asdic) operators.

Army

Armourers, blacksmiths, blacksmiths and welders, boiler attendants, bread bakers, bricklayers and masons, carpenters, chemists, clerks, cooks, coppersmiths, diesel engine maintenance and operators, electricians, engineering cadets, electricians (M.T.), engine artificers, engineering draughtsmen, fitters, instrument mechanics, keyboard operators, mechanics (engine), mechanics (M.T.), mechanists and electricians, operators (signals), painters, panel beaters, photographers, plumbers, printers (litho), projectionists, refrigerator mechanics, sawyers; signal draughtsmen, electricians, fitters and instrument mechanics; tinsmiths, turners, welders, wireless mechanics and X-ray technicians.

Air Force

Aircraft electricians, caterers, cooks (advanced, senior and elementary), coppersmiths, electrical mechanics, electro-platers, fitters, instrument makers and repairers, mess stewards, messing officers, radio mechanics, turners, welders, wireless assistants, mechanics and operators, X-ray technicians.[4]

In all instances the courses were intensive, and generally required full-time attendance for periods ranging from four to twenty-four weeks. From the time the scheme began until it ended in 1945, the number of men trained for the armed forces at sixty different technical colleges and schools scattered throughout the Commonwealth was just on 100,000.

Munitions and aircraft production could not have been undertaken on the scale attempted in Australia during the war without greatly increased numbers of engineering and metal-working tradesmen. The numbers were not so large as for those involved in training servicemen, but the time of training was generally longer.[5] Civilian trainees were divided into two groups:

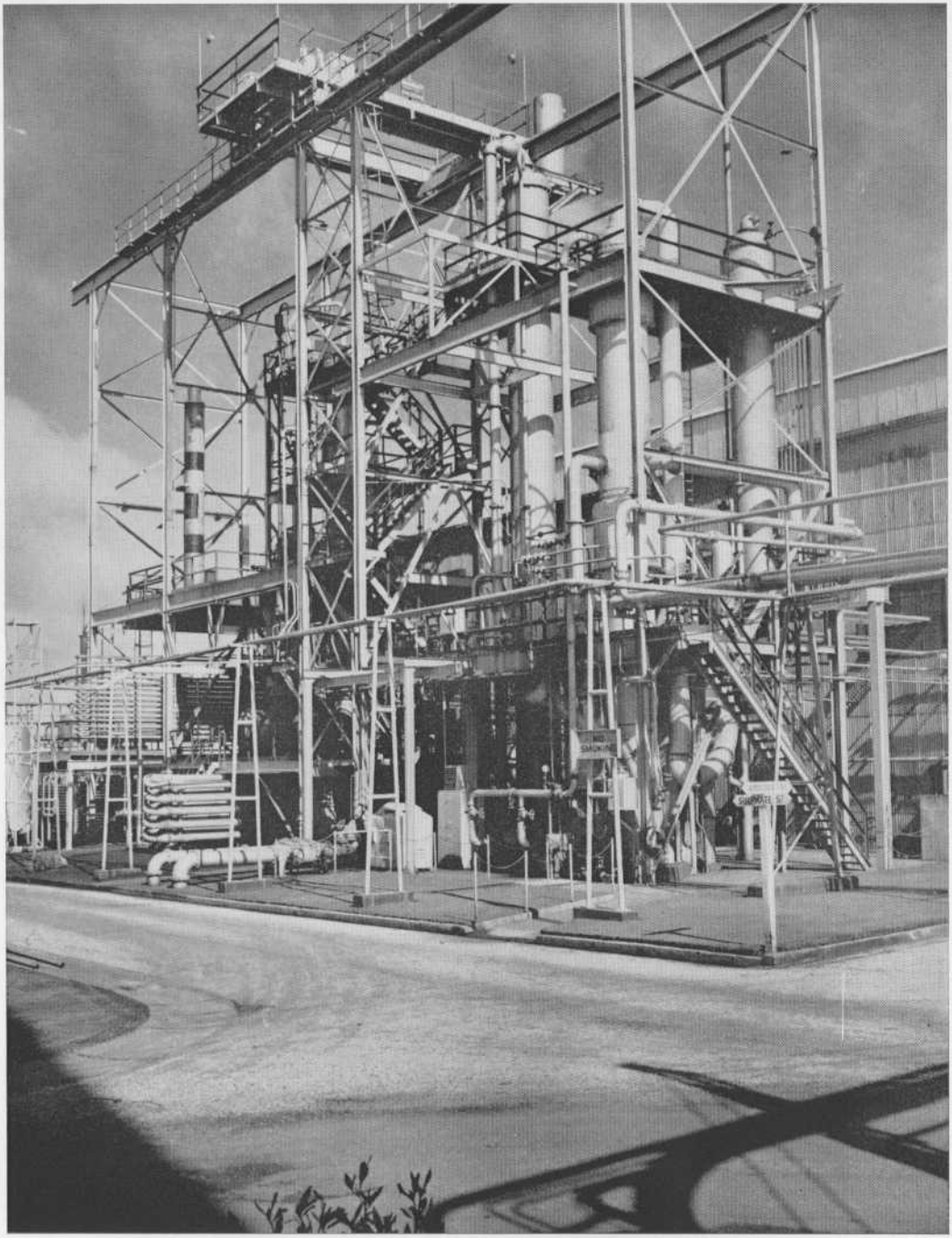
(i) those for whom the nature and extent of training were covered by National Security (Trades Dilution) Regulations;

(ii) those engaged in professional, semi-professional and other courses in which the nature and extent of training were not covered by the National Security (Trades Dilution) Regulations.

The position of the first group was complicated by the fact that having completed their training they would undertake work hitherto carried out only by members of various strong craft unions of engineering and metal trades, admission to which required well-defined standards of skill and much longer periods of training than were being given under the scheme. The problem of finding "a formula for the temporary relaxation of existing customs to overcome difficulties due to shortage of engineering tradesmen for war requirements" was at last successfully solved, mainly through the efforts of Mr Murphy, Industrial Officer to the Department of Supply. Murphy worked out what was essentially an Australian equivalent of the British Dilution Scheme. Dilution of the ranks of skilled tradesmen with men who had undergone short but intensive courses of training ("added tradesmen") was permitted only where insufficient fully trained men were available. In accordance with the Dilution of Labour Agreement, applications were invited from men with at least a primary school education to undergo special courses of training of 44 hours a week lasting from 12 to 24 weeks. Applicants were interviewed and examined, mainly in the evenings by honorary selection committees representing the appropriate employers' and employees' organisations and technical education authorities. Special tests worked out by educational research officers for the purpose of discovering aptitudes for various vocations, will be referred to in a later section. The principal courses given included copper smithing, fitting (general, airframe and aero-engine), fitting (electrical), machining

[4] The list is not complete; altogether 80 different types of course were given for the Services.

[5] The total number was over 23,000.



(*I.C.I.A.N.Z.*)

Synthetic ammonia plant at Deer Park (Victoria).



National Standards Laboratory.



Slip gauges made at the National Standards Laboratory.

(turning, milling, grinding, planing or shaping), pattern making, sheet-metal working, welding (electric, oxyacetylene and aircraft). Every man chosen for training was required to give an undertaking that he would complete the course for which he had been selected, and that he would perform the duties for which he had been trained as required by the Local Dilution Committee for the rest of the war.

Supplementing the training of "added tradesmen" under the trades dilution regulations, many special courses were given to meet the requirements of war production. Foremost among these courses was one for training machine-tool and gauge makers. Selected fitters and turners and first-class machinists were given the opportunity of taking intensive courses of 52 hours a week extending over 3 or 4 months. While undergoing their training these men made thousands of pounds' worth of tools and gauges urgently needed by the government munitions and aircraft factories. Special courses were also given to train men in the skills of grinding lenses for optical munitions. These classes were held in the evening, to avoid interfering with the daily production work. Short courses were also provided in engineering draughtsmanship and industrial chemistry, the latter to meet the demand for chemists in government explosives factories, of which large new units came into operation from time to time.

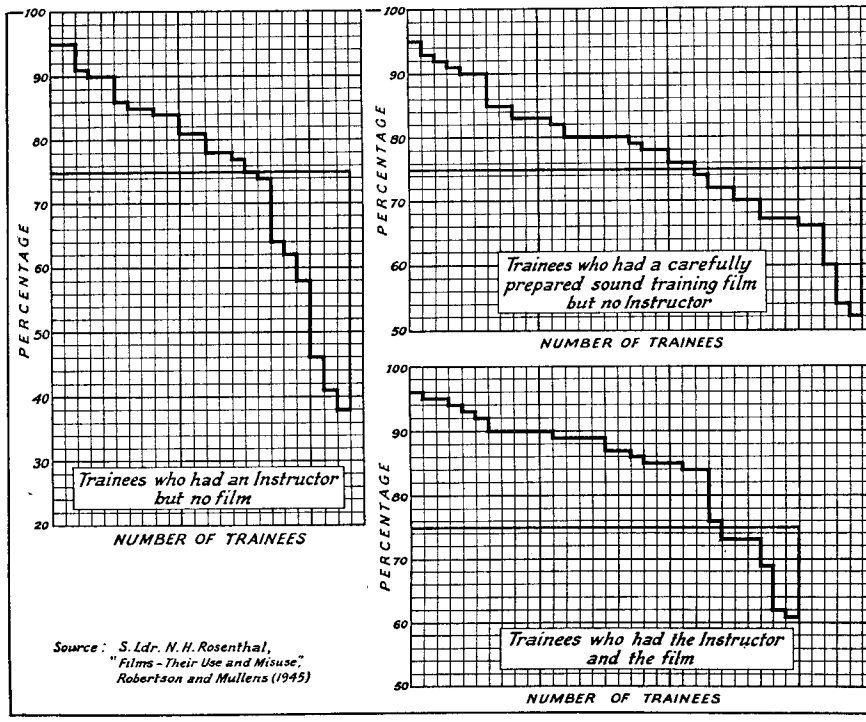
Training of civilian technicians and tradesmen began on 18th March 1940. Of the 24,226 men who undertook classes under this scheme, over 23,000 (or 94 per cent) completed their training satisfactorily. When it is remembered that the failures were due to death, accident, ill health, lack of diligence, enlistment in the Services or general unsuitability, this is a creditably high percentage of successes.

The technical schools and colleges of Australia not only trained some 123,000 men under the training scheme, but kept up their normal yearly intake of 100,000 students. The buildings were often makeshift, the equipment obsolete and the hours long. Through the cooperation of the Services, State education departments, employers' and employees' organisations, and especially through the untiring efforts of the teachers, the technical schools and colleges played an invaluable part in Australia's war effort. This formal training was part of a larger effort, much of which though concerned with lower levels of technical skill, was sustained by industry itself. The training of workers for the explosives factories and the aircraft factories, for example, absorbed a good deal of the energy of foremen and technical officers.

Many factors were responsible for the success of the training scheme, but it would not be possible to analyse them all, or even to place them roughly in order of importance. The few mentioned here are of some educational and scientific interest. Speed and efficiency of instruction were paramount in the scheme, and anything that promised these was certain of consideration. Experiments that could not, because of lack of money, be made on a large scale in peacetime, were now readily supported and launched. One of the most interesting of these experiments was carried

out under the direction of Squadron Leader Rosenthal,[6] Officer-in-Charge of R.A.A.F. Visual Training, on the use of films for instruction in technical matters.[7] His experiments led to the widespread adoption of instructional films.

In one series of experiments 275 trainees, chosen at random, were divided into nine groups of about thirty each. Three groups were instructed on a selected topic by an instructor alone; three others by a film alone, and the last three by a film and an instructor. Typical results, displayed in histograms, are shown in the accompanying figures, from which it will be apparent that the combination of film and instructor produced the most effective teaching.



Some care was needed in the selection of films: for instance, entertaining films were not necessarily the most successful. Rosenthal described experiments with two films, each designed to teach the principle by which the thermionic valve operated: one was most entertaining, the other completely factual. Two groups of trainees were chosen at random (except for the fact that none of them had had previous teaching in the subject),

[6] W Cdr N. H. Rosenthal, BA, BSc. Chemistry master, Xavier College, Melb, 1923-40; Offr i/c Visual Training RAAF 1941-46; Lecturer in Visual Education, Univ of Melb, since 1946. Director, TV Research Program, since 1955. B. Ballarat, Vic, 8 Aug 1898.

[7] N. H. Rosenthal, "Films as an Aid to Science Teaching", *Australian Journal of Science*, Vol. 7 (1944), p. 37.

and one film was shown to each group. Identical tests were then given to each group. The results made it clear that the irrelevancies in the first film had distracted the trainees: the extraneous matter introduced to make the film interesting had in fact defeated its own purpose. The straightforward, purely instructional film gave the better results.

The experience of the R.A.A.F. Visual Training Group demonstrated on a fairly extensive scale, for the first time in Australia, the usefulness of films as a means of instructing comparatively uneducated men in the techniques of industry and in the handling and maintenance of complicated engineering and scientific equipment. After the war the use of instructional films became more general in educational institutions, a few of the more progressive maintaining film libraries, particularly at the primary and secondary levels, and scientific film societies were formed in several States of the Commonwealth.[8]

In any undertaking which involved the training of large numbers of men, it was important that time and energy should not be wasted on trying to train men whose abilities were not equal to the task. In selecting suitable people the psychologist could make a useful contribution, through the medium of intelligence and aptitude tests. The general principle underlying these tests was that evidence obtained by observing a person's behaviour in one or more specially arranged test situations could be used to predict his behaviour in similar situations not yet encountered. The soundness of the assumption that intelligent behaviour and skill assessed in particular kinds of test situation were those required in the school or trade or profession, could be determined only by statistical studies of actual trials. A necessary preliminary, therefore, to the wide-scale application of psychological tests, whether for general intelligence or for special aptitudes, was a study of the correlation between success in the tests and success in desired directions: in some trade or profession.

A systematic study of industrial selection and vocational guidance was begun in New South Wales in 1927 with the setting up of the Australian Institute of Industrial Psychology. Under the direction of Dr A. H. Martin[9] the institute devised batteries or groups of tests generally applicable to industrial purposes, and by 1939 this kind of testing had become well established. In New South Wales psychological tests were used for selection and guidance in schools of the Department of Education, and for vocational guidance by the Department of Labour and Industry. Where the testing was for vocational purposes the procedures developed by Martin were employed. Many of his students later took part in applying industrial psychology to the selection and training of men for the munitions industries and technical branches of the armed services. One of the first instances

[8] The first formed was the Sydney Scientific Film Society, in 1948.

[9] A. H. Martin, MA, PhD. Reader in Psychology, Univ of Sydney; Hon Director, NSW Institute of Industrial Psychology. B. Cosham, Hants, Eng, 9 May 1883. Died 31 Mar 1953.

of this was the system of aptitude testing initiated by Mr Weeden[1] at the Sydney Technical College soon after the introduction of the trade dilution training scheme.

At the request of authorities of the Commonwealth Training Scheme members of the Australian Education Research Council, under the direction of Dr Cunningham,[2] carried out investigations on psychological tests designed to discover the suitability of men for different branches of technical training. One of the first investigations was aimed at devising tests which might help in selecting men for training as fitters and turners. Such tests, it was hoped, would measure a certain type of ability, tentatively termed "mechanical aptitude". Before applying the tests on a large scale it was important to prove that they did measure what they were claimed to measure. This gave the investigators their most difficult problem: that of setting up criteria for judging how well selection tests achieved their objective. Once men had been trained and had entered industry it was not easy to find any large number of them doing the same work under conditions sufficiently alike to enable an objective comparison to be made of their efficiency. To overcome the difficulties of such a "follow up", an experiment was carried out along the following lines.

From about 780 trainee fitters and turners in the Melbourne metropolitan area 140 were chosen, representing in equal numbers the best and poorest of the whole group as judged by their instructors.[3] Some twenty tests were given to each member of the group of 140 and the results examined from the point of view of the ability of these tests to discriminate between "best" and "poorest" trainees. On the strength of the findings a battery of six tests, occupying about two hours and a half, was finally chosen, three tests being used primarily to indicate mechanical aptitude and the other three (including an intelligence test) to provide supplementary information. This expedient was the best that could be devised in the circumstances to discover what, in more leisurely times, would be revealed by the "follow up" process.

As soon as psychologists were confident that, within a small margin of error, psychological tests gave reliable prediction of success in training courses, they extended them to training centres throughout the Commonwealth. Tests were given to as many as 500 men a week, and were used in conjunction with the interview.

Aptitude tests were also used by industry, especially by the Beaufort Division of the Department of Aircraft Production where the problem facing the management was to obtain a large number of skilled workers in a short time from sources consisting entirely of unskilled men. The

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[1] W. J. Weeden, MA. Vocational Guidance Officer, Sydney Technical College, 1936-39; Research Officer, NSW Education Dept, 1940-42; Assistant Director, C'wealth Office of Education, NSW, 1946-53; Director and Chairman, Universities Commn, since 1953. B. Tumut, NSW, 10 Aug 1905.

[2] K. S. Cunningham, MA, PhD. (Served 1st AIF.) Lecturer in School of Education, Univ of Melbourne; Director, Aust Council for Educational Research, 1930-54. B. Ballarat, Vic, 3 Feb 1890.

[3] K. S. Cunningham, *The Scientific Selection of Personnel*, published by the Institute of Industrial Management (1942). See also "The Use of Psychological Methods in Wartime Australia", *Occupational Psychology*, Vol. 17 (1943), p. 111.

tests were used to discover the kind of work prospective employees were best fitted for, rather than simply to choose or reject them. Only those whose responses to the tests were hopelessly poor were rejected outright, and of these most were rejected because of temperamental qualities rather than lack of ability.

In most psychological testing a negative prognosis was usually safer than a positive one. That is to say, people who did poorly in tests but were given the opportunity to do a training course or to enter a particular trade, seldom did well at them. On the other hand, success in the tests was by no means an infallible guide to later performance. Mr Taft,[4] who conducted many aptitude tests for the Beaufort Division, estimated the accuracy of predictions based on tests at about 85 to 90 per cent.[5]

Although the Federal Government had on more than one occasion been advised by several groups of applied psychologists of the desirability of having investigations made into the problems of selecting men for the armed services, practically nothing was done before the outbreak of war. The Services themselves, it appears, were not fully aware that extensive preliminary investigations were necessary if psychological testing was to be of any value. Before the war there was little incentive to use such methods since it was comparatively easy for the R.A.A.F., for example, to select at leisure small numbers of recruits from numerous, well-qualified applicants. But when it was obliged to recruit at high speed large numbers of men from almost every section of the community, the absence of reliable methods for assessing native aptitudes and intelligence, as distinct from acquired skills, was keenly felt by selection committees.

Applicants for enlistment to the R.A.A.F. ground staff were at first required to pass a trade test at which their proficiency would be judged by a competent trade-testing non-commissioned officer; but when as a result of the new manpower regulations large numbers of skilled tradesmen were diverted to the rapidly growing munitions industries, the R.A.A.F. found itself compelled to enlist untrained men and to train them within its own organisation. Similarly, in the early part of 1940 when the Empire Air Training Scheme for air crews was first put into operation, it was found that, while there was a magnificent response to the call for recruits, large numbers of them lacked the education necessary to enable them to undertake the work of the Initial Training Schools.

Only a short time could be given to interviewing each recruit, and education officers at recruiting centres found it very difficult to decide whether a recruit's poor showing was due to lack of ability or merely to lack of education. "The tendency of the Selection Board was quite naturally to be sympathetic towards the smart-looking, city-bred lad, while being very conservative in the selection of country boys whose way of life had

[4] R. Taft, PhD. Psychologist, Beaufort Division, 1941-44; Personnel Advisory Officer, Aust Inst of Management, 1944-49; Senior Lecturer in Psychology, Univ of WA, since 1951. B. Melbourne, 3 Jun 1920.

[5] R. Taft, "Selection and Placement of Aircraft Workers", *Manufacturing and Management*, Vol. 1 (1946), p. 3.

not been conducive to 'putting on a good show' at an interview. The result was that while many potentially good applicants were excluded, an appreciably large proportion of the lads drafted could not cope with the study required of them."

This was the position in October 1940 when the air force was advised by the Air Ministry that in Great Britain the time was considered opportune for introducing some system of aptitude testing as part of the recruiting procedure. Training authorities in the R.A.A.F. acted promptly on this advice and Squadron Leader Naylor,[6] who before the war had been Assistant Director of the Australian Institute of Industrial Psychology, was given the task of devising suitable psychological tests. It was not easy to introduce such tests at this stage of the war (early 1941), since recruiting procedures had by then become firmly established and any innovation that threatened to slow up the process of enlistment would have met with strong opposition. However Naylor was able, with the assistance of the Australian Institute of Industrial Psychology and of Dr Collman[7] of the Victorian Department of Education, to introduce psychological tests to the R.A.A.F., and these tests became a permanent feature of enlistment procedures. In March 1941 a section devoted to aptitude testing was created within the Directorate of Training and placed under Naylor's direction. The directorate concentrated its effort on devising a system for testing applicants who wished to become members of air crews; later its work was expanded to cover selection not only of technical ground staff but of all W.A.A.A.F. musterings and even applications for commissions.

Towards the end of 1942, a Research Section was established in the Directorate of Training. All the psychological and statistical services of the directorate were transferred to this section and it was placed under Wing Commander Clark,[8] who before the war had been Chief Psychologist of the Vocational Guidance Bureau in New South Wales. Under the new organisation the Aptitude Testing Section continued its development and psychological testing became a permanent feature of enlisting procedures.

Psychological counselling methods were introduced early in 1943 to all Initial Training Schools. These methods proved most effective in overcoming the difficult problem of deciding which of the roles—pilot, navigator or gunner—a recruit was best fitted for, and substantially reduced the number of failures in training courses. Psychological techniques were also applied to methods of training and examining aircrew and resulted in many variations of training procedures. In particular, critical requirements for the elementary stage of pilot training were established, and methods of assessment at the pre-solo stage of training were introduced.

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[6] Sqn Ldr G. F. K. Naylor, MA, MSc. Asst Director, Institute of Industrial Psychology, 1930-40; Offr i/c Aptitude Testing RAAF 1941-45; Lecturer in Psychology and Philosophy, Univ of Qld, 1945. B. Sydney, 3 Jun 1906.

[7] R. D. Collman, PhD. Inspector of Secondary Schools, Univ of Melbourne and Vic Education Dept, from 1933. Of Melbourne; b. Melbourne, 1 Jun 1896.

[8] W Cdr J. F. Clark, MA, BSc, PhD. Psychologist in charge Vocational Guidance Bureau to 1941; RAAF Senior Research Staff Officer 1942-46; Senior Selection Officer, C'wealth Reconstruction Training Scheme, 1946-47; Prof of Applied Psychology, NSW Univ Technology, since 1953. Of Sydney; b. Sydney, 20 Apr 1911.

The other main use of psychological tests by the directorate was in vocational guidance. As early as June 1942 a vocational guidance service was opened in the R.A.A.F. under Squadron Leader Jones[9] as part of the activities of the Rehabilitation Section. In 1943 this work was transferred to the Research Section and gradually increased until, at the end of the war, it was the most important function of the section.

Psychological work was not confined to the Directorate of Training. Studies of the psychological effects of anoxia (lack of oxygen) were carried out by Squadron Leader Traylen[1] under the aegis of the Flying Personnel Research Committee; under the same committee Dr Buckle[2] carried out investigations on psychiatric problems of flying.

The army was somewhat slower to set up scientific procedures for selecting recruits. In the first two years of the war testing of military personnel was carried out by psychologists from the Universities of Sydney, Western Australia and Queensland through officers in charge of units, and it was not until October 1942 that a Psychology Service, under the direction of Associate Professor Fowler,[3] was attached to the Directorate of Recruiting and Mobilisation within the Branch of the Adjutant-General. In 1945 an independent Directorate of Psychology, still within the Adjutant-General's Branch, was established. The service examined all recruits for the Australian Army by tests that had been designed by the Australian Council for Educational Research. For a short period the Psychology Service was on trial, but, once it had proved itself, the same weight was attached to the advice of the psychology officer concerning a recruit's mental fitness to serve, as was attached to the advice of the medical officer on his physical fitness. In the main recruits were rejected for two psychological reasons: because their mental age was too low,[4] or because they had grossly unsatisfactory histories of adjustment, such as histories of frank neurotic symptoms or of crime.[5] The proportion rejected averaged about 8 per cent.

Tests applied in the selection of men for training as officers are said to have reduced wastage in this phase of training from 40 to less than 10 per cent. While this figure may be true of candidates sent in soon after enlistment, it would in the opinion of army experts not be true of candidates nominated by experienced fighting units. The latter were tried men—probably sergeants who had already done the job the officer train-

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[9] Sqn Ldr T. G. Jones, BA. Officer-in-charge RAAF Vocational Guidance Sub-section 1944-47; Psychologist, NSW Dept of Labour and Industry. Of Sydney; b. Raymond Terrace, NSW, 8 Aug 1913.

[1] Sqn Ldr N. G. Traylen, BA. Lecturer in Psychology, Univ of WA, 1939, Claremont Teachers' College 1940-41. Psychologist, RAAF Flying Personnel Research Cttee, 1941-46. Of Perth; b Guildford, WA, 24 Mar 1910.

[2] Sqn Ldr D. F. Buckle, MB, BS, BSc. Senior Medical Officer, London County Council Mental Hospitals Dept, 1936-40; Hon Assistant Psychiatrist, Prince Henry's Hospital, Melbourne, 1945-53. B. Melbourne, 7 May 1911.

[3] H. L. Fowler, MA, PhD. (Served 1st AIF.) Assoc Prof of Psychology, Univ of WA, 1938-46. B. Hemel Hempstead, Eng, 5 Oct 1891. Died 27 May 1946.

[4] This was at first set at a Binet mental age of 10; it was later raised to 11½ years.

[5] D. W. McElwain, "The Application of Psychological Methods to the Armed Forces". This article appeared in *The Progress of Psychotechnics*, edited by F. Baumgarten, and printed in Switzerland.

ing unit was to train them for; wastage among such men was probably almost nil.

Admission to the Royal Military College and selection of commandos, paratroops and apprentices for skilled trades were all based to some extent on psychological testing. Altogether the Army Psychology Service made some 350,000 tests in the four years of its existence. Unfortunately the main body of the Australian Army had been recruited before 1942, so that the opportunity of using the Psychology Service when it was most needed was missed.

The navy, concerned as it was with a much smaller body of men than either the army or the air force, and with more recruits to choose from than it could absorb, found that its traditional methods enabled it to select a good proportion of high-quality men. Even so the navy began to make some use of psychological tests towards the end of the war.

In 1943 the Sydney Technical College began to apply psychological tests to disabled servicemen sent to it by the Repatriation authorities for training. Under the direction of Mr O'Neil[6] this work was organised so that men were interviewed and tested while still convalescing in hospital. This activity was later greatly expanded until it became part of the formal selection procedure of the Commonwealth Reconstruction Training Scheme.[7]

In general there were few if any attempts by Australian psychologists to undertake programs of research directed to improving training methods. Neither did they join the teams engaged on research into weapon utilisation. Their efforts, characteristic of most of the pre-war application of psychology in Australia, centred almost entirely on the use to be made of individuals. While no technical developments were made which could be regarded as of outstanding theoretical importance, psychologists did succeed in establishing on an empirical basis the limits of the applicability and usefulness of tests under Australian conditions. Perhaps the best indication of their impact on the military side was that after the war all three Services established permanent psychological organisations. The overall result was that applied psychology emerged from the war period with a greatly enhanced status in the commercial and industrial world, and in the next decade found much wider use.

Up to the time Professor Ashby and Dr Vernon began their investigations into the use of scientists in the war effort, in the latter part of 1941, little had been done in Australia to investigate the effect of hours and conditions of work on industrial efficiency. Public attention was drawn to the drop in production which followed undue lengthening of hours of work, a specific case being that of the employees of the Commonwealth

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[6] W. M. O'Neil, MA. Psychologist in charge, Vocational Guidance Bureau, Dept of Labour and Industry, NSW, 1936-40; Vocational Guidance Officer, Sydney Technical College, 1940-45; Prof of Psychology, Univ of Sydney, since 1945. B. Sydney, 15 Jun 1912.

[7] W. M. O'Neil and J. P. Young, *Vocational Guidance of the Disabled Serviceman*, Govt Printing Office (1944).

Steel and Forge Company, which came before Mr Justice O'Mara[8] in the Arbitration Court in March 1942.

The influence of hours of work and fatigue on output in the munitions factories had been thoroughly studied in Britain during the war of 1914-18, when the inefficiency of very long hours (up to 90 a week) was clearly demonstrated. After that war similar work was done in almost every branch of industry, not only in Britain but also in the United States, always with very much the same results: that output fell off seriously if working hours were made too long. In the early days of the war of 1939-45, suggestions were made that similar studies should be carried out in Australia to see whether the findings of oversea physiologists and psychologists could be applied locally without modification. Dr Murray,[1] Principal Medical Officer of the Department of Munitions, consistently opposed these suggestions, taking the view that efforts should be directed to applying what was already known rather than to attempting to confirm that knowledge all over again.

In their report to the Prime Minister, Ashby and Vernon recommended that the Department of Labour and National Service should appoint officers qualified to conduct surveys of industrial physiology. The outcome was that Murray was appointed Controller of Factory Welfare to direct investigations into such problems as the optimum conditions of temperature, humidity, lighting and ventilation for maximum productive efficiency.[2] The Standards Association had just published its Emergency Lighting Code, and one of the controller's first tasks was to see that this code was put into operation; another was to initiate a study of dust hazards in foundries, which had been greatly accentuated by wartime conditions.[3] The very pressing problem of the high incidence of dermatitis in fuse-filling sections of explosives factories, which at one time seriously threatened to hold up the production of much-needed explosives, was also studied and procedures were drawn up that contributed greatly to reducing the risks attached to this work.

The psychological factors influencing the worker's human environment had been seriously studied for the first time in Australia by the Victorian Education Department's Advisory Committee on Training, Foremanship and Industrial Management, which, under the chairmanship of Mr Eltham, was responsible for introducing courses of instruction in the subject at Melbourne Technical College in 1938, and later at other technical colleges. The war provided a new stimulus. While inspecting the leading aircraft factories in Great Britain and the United States in 1941, Mr Storey,[4] who

[8] Mr Justice T. O'Mara. (Served 1st AIF.) Judge of C'wealth Arbitration Court 1939-46. B. 1898. Died 12 Oct 1946.

[1] Dr H. D. M. L. Murray. Principal Medical Officer to Dept of Munitions 1940-42; Controller, Factory Welfare Branch, Dept of Labour and National Service, 1942-45. Director of Public Health, Tasmania, since 1951.

[2] H. D. M. L. Murray, "Hours of Work and other Factors Affecting Industrial Efficiency", *Journal of the Institution of Engineers*, Vol. 13 (1941), p. 215.

[3] A. A. Ross and H. N. Shaw, *Dust Hazards in Australian Foundries*, issued by the Dept of Labour and National Service; reprinted 1948.

[4] Sir John Storey, BSc. Director, General Motors-Holden's, 1934-40; Director Beaufort Division, Dept of Aircraft Production; Managing Director Overseas Corp (Aust) Ltd; Chairman, Immigration Planning Council, 1949-55. B. Sydney, 1 Nov 1896. Died 3 Jul 1955.

for some years had been interested in industrial management, and had in fact served on the above advisory committee, was so impressed with the influence of management on the efficiency of the aircraft industry that on his return to Australia he strongly urged that still greater attention should be paid to the subject. When, shortly afterwards, the Institute of Industrial Management, Australia, was formed, Storey was elected its first president. Branches were later set up in all States.

The aim of industrial management as formulated by the institute, was to "select, train and direct executives, to build and sustain the morale and team spirit of employees and to create and weld together all the varied units essential to efficiency and perfectly coordinated operations". Soundly based industrial management undoubtedly exercised a powerful and beneficial influence on production. It would be difficult to assess what effect the growing interest in the subject had on wartime industry; the important point was that industrial management had come to stay.

The list of occupations set out in the Reserved Occupations Order made by the Minister for Defence Coordination on 18th March 1940 included so many branches of science seemingly quite remote from the war that it was reasonable to conclude that the Government's policy was to exempt practically all scientists from military service. However, until January 1942 when the Directorate of Manpower was established, the list was not mandatory and it was open to anyone to seek release from his reserved occupation. It was left to the individual scientist to discover where and how he could best serve his country. During the first two years of the war the expansion in the activities of government departments such as the Munitions Supply Laboratories and the Council for Scientific and Industrial Research, absorbed increasing numbers of scientists. In spite of this, however, there was, especially among scientists not in government employ (and this included the large numbers of research workers and men of the highest rank in their professions), a sense of disappointment and frustration that more use was not being made of their services in the war effort.

In the course of their inquiry Ashby and Vernon discovered examples of misplaced scientific manpower. They noted, for instance, that an entomologist was released from the New South Wales Department of Agriculture to enlist in a mechanised unit at a time when there was a great need for entomologists in the army. Similarly, when there was urgent need for advice on vegetable seed production, experts on this subject were being allowed to enlist in Service units in which their knowledge would not be used. Little use was then being made of statisticians in the army or in the Department of Labour and National Service, where their work could have considerable importance; geographers, geologists and psychologists were not being used for work that urgently needed doing in their own fields. It would be wrong to conclude that this failure was general. It was not. Full use was being made of the country's physicists in the development of radar and of optical munitions: in fact, there was a shortage of physicists. Much the same was true of chemists.

While Ashby and Vernon were making their investigations, the War Cabinet set up the Directorate of Manpower, to be administered by Mr Wurth,[5] who was given "the power to exempt persons from service or to prohibit their enlistment; the power to prevent employers from engaging labour not authorised by the directorate and to restrict the right of employees to engage in the employment of their choice; the power to prevent employees from leaving their employment and to restrict the right of the employer to dismiss his employees; the power to direct any person to leave one employment and engage in another; and finally, the power to compel individuals to register and provide information about themselves".

Ashby and Vernon believed that these onerous responsibilities, as far as they affected scientists,[6] could not be soundly administered without the aid of the scientists themselves. They were in favour of appointing an adviser on scientific and technical manpower to the staff of the Director-General of Manpower. In this they were strongly supported by both the Australian National Research Council and the Institution of Engineers. The need for such an appointment appeared so pressing that Ashby and Vernon did not wait for the publication of their report. On 13th March 1942, together with representatives of the two scientific bodies just mentioned, they conferred with the Director-General of Manpower, who readily assented to their proposals. Professor Clunies-Ross[7] was appointed Adviser on Scientific and Technical Personnel (later Director of Scientific Personnel) and given the responsibility of disposing of manpower resources to the best advantage by

(*a*) preparing estimates of the numbers of trained men (scientists and technologists) required by the Services;

(*b*) estimating the numbers of similar men required for Munitions and other government departments;

(*c*) estimating the minimum reserves of technical and scientific personnel required to maintain minimum essential civilian services;

(*d*) determining the technical and scientific personnel available for transfer to war activities;

(*e*) recommending the amplification or modification of existing resources and methods of training;

(*f*) examining the selection and reservation of manpower required to meet national needs;

(*g*) preparing an organisation for determining the allocation of technical personnel in the national interest.

On the assumption that the problem of deciding whether scientists should work for the Services or for industry could probably best be decided by those possessing special knowledge of the branches of science

[5] W. C. Wurth, CMG; LLB. (Served 1st AIF.) Industrial Registrar 1932-36; member NSW Public Service Board 1936-39; Director-General of Manpower 1941-44; Chairman, NSW Public Service Board, since 1939; Chancellor, NSW Univ of Technology, since 1949. B. Mudgee, NSW, 14 Jan 1896.

[6] The term scientist is used here in a wide sense to cover virtually anyone holding at least a bachelor's degree in a science, pure or applied.

[7] Sir Ian Clunies-Ross, CMG; DVSc. President, Australian Institute of International Affairs, 1941-45; Prof of Veterinary Science, Univ of Sydney, 1940-46; Chairman, CSIRO, since 1949. B. Bathurst, NSW, 22 Feb 1899.

concerned and that each case should be judged on its merits, the Director of Scientific Personnel sought the help of scientific and professional organisations. In May 1942 he asked a number of them to send in the names of those of their members who were willing to serve on advisory committees. The following organisations responded to his appeal: the Australian National Research Council (A.N.R.C.), the Institution of Engineers, the Australian Chemical Institute, the Institute of Physics, the Australian Institute of Agricultural Science, the Australian Veterinary Association, and the Australian Association of Scientific Workers. By August 1942 five Central Advisory Committees (with corresponding State sub-committees), all voluntary, were constituted to advise on the allocation and control of engineers, chemists, physicists, agriculturalists and veterinarians. Members of the National Research Council and of the Association of Scientific Workers formed a committee to deal with questions relating to geologists, botanists, zoologists, physiologists, biochemists, mathematicians, and to alien scientists.

The State sub-committees made recommendations to the Deputy Director of Manpower in their respective States on (i) action to be taken in individual cases referred to them by National Service officers, and (ii) whether a scientist could best help the war effort by enlistment, employment in industry or by engaging in scientific research. The Central Advisory Committees coordinated the work of the State sub-committees and advised the Director-General of Manpower on questions of policy relating to training and employment of scientists throughout the Commonwealth.

In the beginning some committees concerned themselves solely with holders of degrees and diplomas and with senior students, but on 24th February 1944 the Director-General issued instructions that advisory committees were to include in scientific manpower all students doing part-time diploma courses in engineering or any branch of science. Once the committees had begun to operate, the Services were invited to submit to the Director-General of Manpower estimates of the numbers of men required for their scientific and technical branches. The Services agreed not to accept any such men for enlistment without first consulting the Director-General. Thus the responsibility of meeting Service requirements in these respects fell upon the Directorate of Manpower.

Commonwealth departments employing scientists, notably the Department of Munitions and the Council for Scientific and Industrial Research, were similarly asked to estimate their requirements. At first these departments were reluctant to relinquish their right to engage scientists of their own choosing, but the principle was eventually established that all movements of scientists should be subject to review by the Manpower Directorate, and a full measure of cooperation along these lines was established between the directorate, the Services, government departments and private industry. Some difficulties were experienced when the advice of Scientific Manpower Committees on the transfer of engineers and chemists from the Munitions Supply Laboratories to the technical branches of the Ser-

vices conflicted with the recommendations of the Public Service Manpower Committee,[8] but appropriate procedures were eventually devised to overcome most conflicts. When these procedures failed the decision was made by the Director-General of Manpower. On matters of manpower his word was final.

The great advantage of the system of advisory committees was that when it came to deciding where and how they could best serve their country's wartime needs, scientists were judged not by a single non-scientific person in absolute authority but by an impartial tribunal of their peers. The flexibility of the system enabled scientists to be treated as individuals, each according to his merits, and the evils of regimentation were thus avoided. It has been said, for example, that the Germans, who tried a much greater degree of regimentation than any of the Allied nations, obtained nothing like the help they might otherwise have had from their large numbers of highly gifted scientists.

The most active of all the advisory committees, at least in terms of numbers dealt with, was the one on engineering. With a central committee located in Sydney and sub-committees in each State and in Newcastle, the work, especially at the time of the rapid expansion of the munitions program in 1942, proved too much for honorary committees whose members were all senior men holding important positions. Mr J. G. Thornton, a highly qualified engineer, was therefore appointed as Engineer Executive Officer. In order to lighten the sub-committee's work of making the necessary detailed inquiries about individual engineers, panels of reference officers nominated by branches of the Institution of Engineers were set up. With the help of this organisation sub-committees were able to allot to the Royal Australian Engineers, the Corps of Australian Electrical and Mechanical Engineers, and later to the Royal Australian Air Force and the Royal Australian Navy, some 500 or more engineer officers.

The Engineering Committee, in consultation with university appointments boards and teaching staffs, arranged for the allocation of graduates in engineering as they became available. There was of course no suggestion of dragooning in these arrangements: reference officers would first discuss with a student his future intentions, and obtain from the university staff an assessment of his capabilities. Having before it full information concerning vacancies and their relative importance, the advisory committee was able to allocate the newly graduated engineer in the way it thought best. Every effort was made to see that the right man went to the right place, and that there was no wastage of manpower. For example, at the instigation of the Director of Scientific Personnel, and with the cooperation of the National Research Council, the Engineer Executive Officer investigated the employment of some forty alien engineers and scientists who had been called up for service with the Civil Aliens Corps. These investigations showed that in every case these alien scientists were employed on work of considerable importance to the war effort, and on

[8] Set up to review the employment of all officers in the Commonwealth Public Service.

the advice of the Manpower Directorate all except a few about whom the security services entertained some doubts were allowed to continue in their work.

The Central Chemical Advisory Committee was established at the head office of the Australian Chemical Institute in Melbourne. In contrast to the large demands made by the Services for engineers, the call for chemists was rather small. The procedure followed by the Committee of Chemists was much the same as that used by the engineering and other committees: a survey was made to discover the types of chemist likely to be in short supply. In this way it was hoped that steps could be taken to meet any deficiency.

Other sub-committees worked in the same close cooperation with university staffs as did the Engineering Sub-committee, and consequently the university authorities became aware of those categories of manpower in short supply. The numbers of engineers, physicists, doctors and dentists were always insufficient to meet demands, and the universities' assessments were used to influence decisions on the numbers of students to be accepted in different faculties. The estimated requirement of young graduates in engineering for the Services and for munition factories was 250 and 350 for the years 1942 and 1943 respectively; the numbers of engineers graduating in those years (from all Australian universities) were 105 and 109. The shortage of physicists was also particularly acute. An estimated output for 1942 of between forty and fifty university-trained physicists was considerably reduced by students' abandoning their degree courses to enter courses of training in radar for the R.A.A.F., with the result that the demand was about three times as great as supply. The shortage of chemists was not so acute: approximately 200 students in science with chemistry as a major subject graduated in 1942, and about half of these went to munitions factories; the rest went to private industry.

There were also severe shortages of entomologists, who were needed by the Army Medical Corps for mosquito control in the prevention of malaria; of geologists to meet the requirements of the newly-established Mineral Survey; and of bacteriologists[9] and biochemists for food preservation and other industries. Outstanding among the many deficiencies in scientific manpower were chemical engineers, and, in general, men trained at the higher technological levels. Australia was not alone in this predicament, as very similar deficiencies were felt in Britain. Since such training could not, by its nature, be improvised, little or nothing could be done during the war to make good the deficiencies of higher education in technology. The steps that were taken after the war will be described in the last chapter.

In order to help the advisory committees make the most of the relatively small numbers of scientists available by directing them where they were most needed, the Director-General of Manpower made registration com-

[9] Courses in non-medical bacteriology at Australian universities were not begun until after the war.

pulsory for a number of professions. Early in the war various scientific organisations had carried out voluntary surveys of scientists in their own particular groups. These surveys suffered from two defects: they were neither complete nor kept up to date. These defects arose mainly because the organisations lacked the authority to make registration compulsory and the financial resources to carry out all the work involved; the surveys did not include members of the profession who were not members of the organisation.

By appeals through the press, radio and professional organisations, the compulsory and presumably complete registration ordered by the Director-General of Manpower was carried out for the following groups: engineers (April 1943), and chemists, pharmacists, psychologists and dentists (August 1943).[1] By the middle of 1944 the following numbers of men and women were registered in the different groups:

Engineers . . .	18,383;
Chemists . . .	4,640;
Pharmacists . . .	4,874;
Psychologists . . .	1,557.

The number of psychologists, which may seem surprisingly large, may be explained by the fact that in order to meet the demands of aptitude testing and vocational guidance in the Services and in industry, graduates with only two years' training in the subject were classified as psychologists.

With the aid of a staff of girls, Miss Turner,[2] an experienced statistician on the staff of the C.S.I.R., transferred the information on the 29,454 forms to cards, punched on the Copechat System and designed to yield information either for surveys or in respect of individuals. The transfer, made by hand punching, was a slow and tedious business made the more so by the inexperience of the girls employed on it. Nevertheless, after a sustained and creditable effort, the task was completed in time for some use to be made of the system: to discover, for example, chemists experienced in paint manufacture, engineers with cost accountancy experience, engineers with experience of conveying and handling road-making gear and machinery. The punched-card system was used also to institute an equitable distribution of pharmacists and dentists between the Services and the civilian population. From another survey details of the professional training of 1,000 engineers were made available to the Royal Australian Engineers and to the Royal Corps of Australian Electrical and Mechanical Engineers, to help them in the selection of officers. Compulsory registration gave scientific organisations an opportunity to test the coverage of their unofficial voluntary surveys. The Australian Chemical Institute, for example, discovered that its survey covered only about 1,500 chemists, whereas 4,640 registered under the compulsory survey.

[1] The information asked for covered: (*a*) Type (civil, electrical or mechanical engineer); (*b*) Academic qualification; (*c*) Age (10 age groups were used); (*d*) Salary (5 intervals); (*e*) Nationality; (*f*) Dependents; (*g*) Employment; (*h*) Health and physical fitness.

[2] Miss Helen Newton Turner, BArch. Mathematical Statistician, with CSIR, to 1942, with Dept of Home Security to 1943; Officer-in-charge, Register of Scientific Personnel, Directorate of Manpower, 1943-45. Of Sydney; b. Sydney.

Unfortunately the register of scientific personnel was begun late and covered only a small number of categories. It was therefore not as useful as similar but more complete registers compiled in Britain and the United States. Worse still, the register was allowed to lapse immediately after the war, just when it might have been used to predict the needs for scientists in different fields and so enable the universities to adjust their programs to meet those needs. When, some six years after the war was over, proposals were revived for the compilation of a really comprehensive scientific register, not even the whereabouts of the punched cards of the wartime survey could be discovered. All of which lends point to the cynic's comment that the only lesson of history is that man learns nothing from history.

The question arises whether the scientists themselves could not have done more about the matter both during and after the war. The Central Scientific Register in Britain was sponsored by the Royal Society but was subsequently taken over and administered by the Ministry of Labour and National Service; the American Roster of Scientific and Trained Personnel was compiled by the United States Government through the joint agency of the National Resources Planning Board and the Civil Service Commission. The only body in Australia in a position to represent scientists as a whole during the war and at the time of the revived proposals for a central register, was the Australian National Research Council, which although it had been largely instrumental in persuading the Director-General of Manpower to set up the Scientific Personnel Section, had neither the money nor the prestige of similar bodies in Britain and the United States. Even if it had had both, the element of compulsion that inevitably enters into the registration of manpower is such that at some stage it would seem the authority of the Government must be invoked.

Apart from intensifying some degree courses by shortening their duration (as was common in medical courses), there was little change in the training of students in reserved faculties in the universities. As a rule only a small degree of intensification proved feasible, and in some instances where it was attempted it was later abandoned because in trying to cover the same ground in a shorter period than was customary, conditions of fatigue were experienced similar to those observed in industry when unduly long hours were worked. However, some important and lasting changes did take place in the recruiting of students in science and related faculties. Until 1942 students in reserved faculties (medicine, science, engineering, dentistry, and agricultural and veterinary science[3]) were selected in order of merit, assessed by a public examination.[4] In accordance with the National Security (Manpower) Regulations, universities were directed that the total number of students to be admitted to the first year, taken together,

[3] Also pharmacy students in the last two years; final year students in modern languages; post-graduate and research students in faculties wholly reserved or engaged in research initiated or approved by the Government.

[4] C. Sanders, "Student Selection and Academic Success", Commonwealth Office of Education, Education Series No. 1 (1948).

should not exceed the average of the preceding three years, and that this total should be divided among the faculties as the university thought fit, provided that the number admitted to engineering was in no case reduced below the number admitted in 1941.

During the operation of this system in 1942 it became apparent that not enough students were entering the universities, and that many capable students were unable to apply for enrolment in university courses because of their economic circumstances. A widely current view was that the rate of wastage through failures could be greatly reduced if a larger proportion of students of high merit was enabled to attend the universities. The number of university students enrolled in Australian universities before the war (roughly 14,000) was not high on a population basis, when compared with other English speaking countries, for example Scotland, New Zealand and the United States. The enrolment of 14,000 represented about 1.25 per cent of the total primary and secondary school population. Education authorities, however, estimated that after taking into account intelligence and other factors considered necessary for academic success, not less than 8 per cent of the school population was capable of study at the tertiary level.[5] If this proportion of the Australian school population had been admitted to the universities, the number of students would have risen to 90,000. There was thus a large untapped reservoir of talent. At the same time it was clear that if the limited training facilities available at the universities were to be used to the best advantage for the war effort, there would have to be greater control over the quality and number of students entering different faculties.

The Government therefore decided, on 24th September 1942, to set up an inter-departmental committee consisting of representatives of the Department of War Organisation of Industry, the Director-General of Manpower, the Department of National Service, and the Treasury, to review university policy generally. The committee's report confirmed that there was a shortage of men and women with university training; that one of the major reasons for this shortage was the financial handicap which debarred many able students from entering universities; that if sufficient financial help was given adequate numbers of students would be forthcoming. Accordingly, on the strength of this report the Government decided on 29th October 1942 that financial assistance should be given to students in science, medicine, dentistry, engineering, veterinary and agricultural science, such assistance to be subject to a means test. Students so assisted were to be called upon to enter a bond to serve the Commonwealth, if required, for up to three years.

The most important outcome of the inter-departmental committee's deliberations was the Government's decision to administer this scheme

[5] This figure (quoted by Sanders) is based on the assumption that students with an I.Q. of 115 or over are capable of undertaking university work. Estimates by the Australian Council of Educational Research indicate that 16 per cent of the school population falls into this category. But intelligence alone will not guarantee a successful university career; character and personality are factors in academic success, and Sanders found that by taking them into account the 16 per cent was halved.

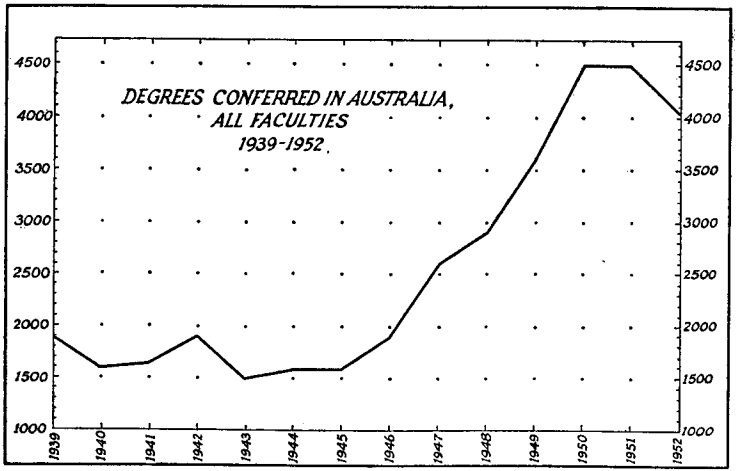
by means of a Universities Commission,[6] whose function it would be to advise the Minister for War Organisation of Industry on matters relating to universities and education; in particular it was to advise the Director-General of Manpower on exemption of students and staffs of universities from other forms of national service; to deal with questions of employment of university graduates, financial assistance to students, and regulation of university enrolments. In this last matter some difficulties arose. The Universities Commission, in consultation with the Director-General of Manpower, fixed the quotas of students to be admitted to the various faculties. Acting on these instructions the universities refused to enrol more students in reserved faculties than those provided for in the quotas. This led to litigation in the High Court, the outcome of which was that the regulation governing quotas of the Universities Commission Regulations was declared to be invalid, on the ground that a law relating to education could not be justified under the defence powers of the Commonwealth. The Commonwealth Government thus had no power to control the educational policies of the universities.

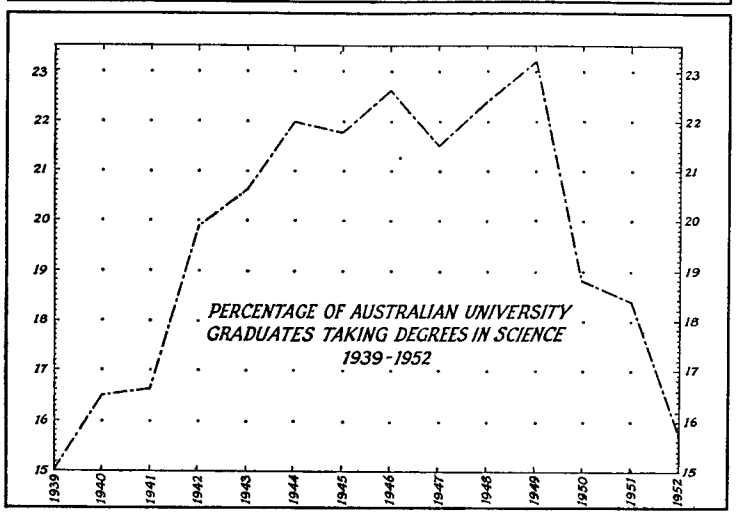
Any disorganisation that might have occurred in the universities with the resulting influx of students in 1943 was forestalled by the Director-General of Manpower, who by exercising his authority under Manpower Regulations (No. 13) prevented students not already enrolled from enrolling, and prevented students already enrolled from transferring from one faculty to another. Furthermore, the Minister for War Organisation of Industry directed that financial assistance was to be limited to those students already in approved quotas, so that in the end the result aimed at by the universities was achieved: that numbers of students in reserved faculties were restricted to the prescribed quotas.

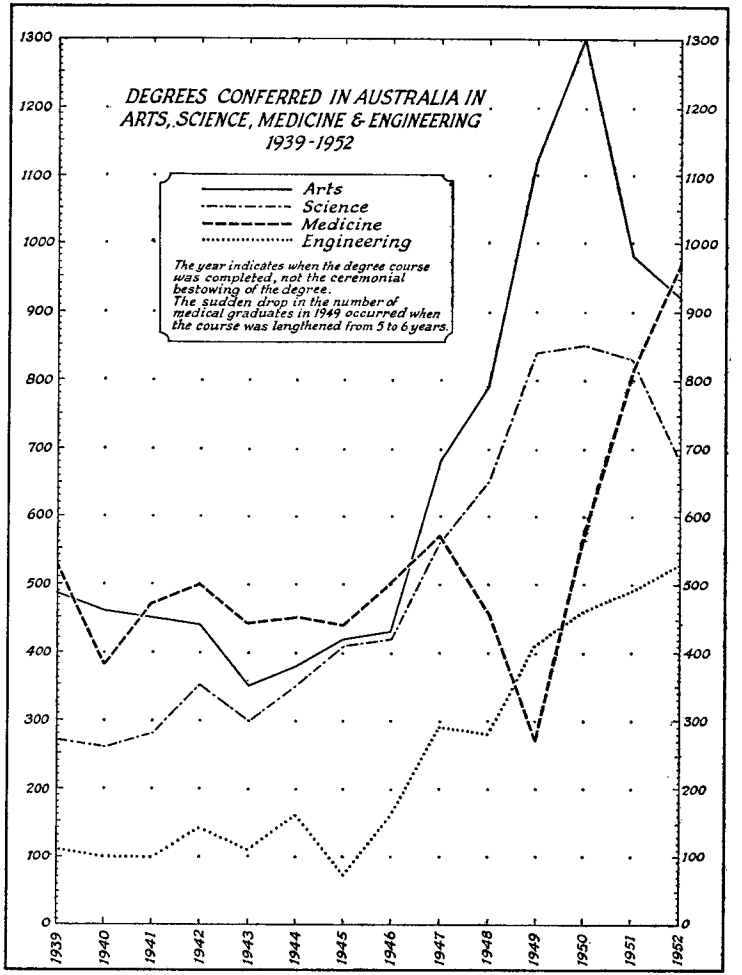
Contrary to expectations, the wartime methods of selecting prospective university students—methods designed to increase the proportion of abler students—did not reduce the wastage through failure at the university. The possible gains from a higher degree of selection were no doubt offset to some extent by the effects of a shortage of teaching staff, many of whom were occupied in other war services. University examiners seemed to raise their standards, though in all probability not deliberately, so that about the same proportion passed as previously. There is no doubt, however, that the quality of the student body was raised in the sense that students progressed through degree courses with fewer supplementary or deferred examinations and with a greater proportion of credits and distinctions.

An interesting trend in the proportion of students taking degrees in science—one, so far as can be determined, not deliberately encouraged by any official action—may be seen in the accompanying graph. Apart from a temporary surge in 1942 when the number returned to the pre-war level, the total number of students graduating in all faculties from Australian universities each year remained fairly steady, at about 1,700, as is illustrated. Over the next five years there was an extremely rapid

[6] Under the National Security (Universities Commission) Regulation made on 3 Feb 1943. Prof R. C. Mills was its first Chairman.


DEGREES CONFERRED IN AUSTRALIA,
ALL FACULTIES
1939-1952
4500
4000
3500
3000
2500
2000
1500
1000
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952


PERCENTAGE OF AUSTRALIAN UNIVERSITY
GRADUATES TAKING DEGREES IN SCIENCE
1939-1952
23
22
21
20
19
18
17
16
15
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952


DEGREES CONFERRED IN AUSTRALIA IN
ARTS, SCIENCE, MEDICINE & ENGINEERING
1939-1952
Arts
Science
Medicine
Engineering
The year indicates when the degree course was completed, not the ceremonial bestowing of the degree.
The sudden drop in the number of medical graduates in 1949 occurred when the course was lengthened from 5 to 6 years.
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952

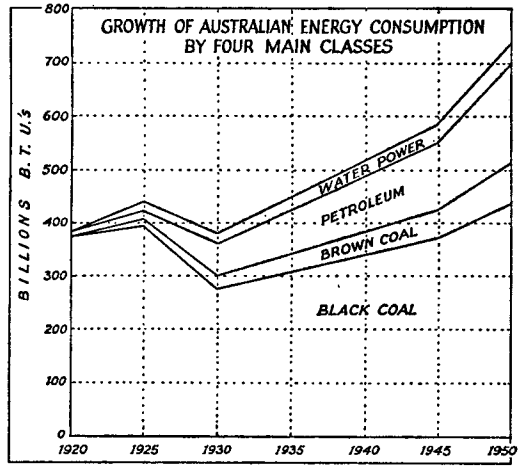
rise, from which it would be reasonable to conclude that a large proportion (it would be impossible to give a precise figure) of those who failed to take or complete degree courses during the war were able to do so afterwards. The fluctuations in the numbers of students graduating in the four largest faculties during the war and for several years after it, are shown in an accompanying graph.

In spite of the initial setback it received, the Universities Commission, by its methods of selecting students for the universities, greatly assisted not only in sustaining the numbers of graduates in science and engineering, but also in maintaining high standards.

CHAPTER 10

FUEL AND POWER

THE extent of a nation's industrialisation and its general standard of living were to a large extent reflected in its consumption of power. This in turn depended very much on its ability to produce or to acquire the fuels which formed the material basis of power—coal and oil.[1] In comparison with other nations, Australia in 1939 was not unusually rich in the sources of power, nor was its per capita consumption exceptionally large. In the consumption of electrical energy it fell well below the United States, the most highly industrialised nation; there in 1939 electrical energy was consumed at the rate of 807.4 kilowatt hours per head per annum. Similar figures for Australia (571.4 kilowatt hours) compared favourably with those for Britain (538.1). This comparison should be qualified by pointing out that in both the United States and Britain a good deal of fuel was used to overcome the cold, which is generally speaking more severe than it is in Australia. On the other hand, more power was used for transport in the United States and Australia than in the United Kingdom. Because of its great size and widely scattered population, Australia spent a disproportionately large amount of power in transport—more than one third of the power was used for this purpose. Any attempt to assess her efforts to manufacture munitions and to function as a supply base in the Pacific should be made with this limitation in mind.



Power in kilowatts
1 BTU = 0.000293 kilowatt hours
1 kW = 0.949 BTU per second
1 hp = 0.7452 kW.

In ascending order of importance the three main sources of energy, excluding such materials as firewood and bagasse, were water for the generation of electric power; oil, for transport—trucks, cars, aircraft, and ships; and coal, for the generation of electric power, transport and many other purposes. The proportions in which Australia used

[1] Not all fuel was used to generate power; much coal, for example, was used in the extraction of metals and for domestic purposes. In this chapter, however, the main concern is with fuels as a source of power.

these three sources conformed with the general world pattern, as may be seen from the accompanying approximate figures for the year 1940:

	Coal	Petroleum	Natural gas	Water
World average . .	71.1%	17.8%	3.9%	7.2%
Australia . . .	73%	21%	nil	6%

The growth in the consumption of power in Australia from the main sources is shown in the accompanying figure.[2]

COAL

Coal, contributing as it did nearly 75 per cent of all power, was the mainstay of Australian industry, for which reason the extent of its production tended to put sharp limits to the level at which the manufacture of munitions could be sustained. In almost every part of the world the coal industry had long been bedevilled by industrial strife, arising presumably from similar root causes: the dangers and discomforts, fear of unemployment, and, as the miners believed, inadequate rewards. The subject, as Mr Justice Davidson,[3] the foremost authority in Australia on industrial relations in the coal industry, once remarked,

> does not lend itself to scientific analysis. The essential facts include states of mind deducible only from overt acts and their results and are therefore in some degree argumentative. The theories of philosophy, economics and psychology too, only impinge upon and may be neutralised by any one of the myriad unpredictable eccentricities of human behaviour individually or in the mass. So there is met the most difficult of all problems, the solution of the human equation in modern industrial conditions such as those in the coal industry.[4]

Australia was no exception; if anything, she had more than her share of troubles of this kind. Nor did the outbreak of war exercise any marked restraining influence on the frequency of industrial disputes in the coal mining industry. Before the war these had arisen mainly over hours of employment and wages, but during the war they were due in a surprisingly large number of instances to matters which seemed to have no association with owner-employee relations. Protests against government regulations, against decisions of industrial authorities, against instructions or actions of the Miners' Federation itself, were common. Disputes over working hours were responsible for strikes lasting from 11th March to 20th May 1940, during which the estimated loss of coal was 900,000 tons.

In February 1941, after some earlier tentative and relatively ineffective attempts to control the industry, the Government, alarmed at the diminu-

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[2] The figure is taken from H. Rabling, *Energy for a Greater Australia* (1950).

[3] Hon Sir Colin Davidson. Justice, Supreme Court of NSW, 1927-48; Chairman, Royal Commissions on Coal Industry, 1929-30, Safety and Health of Workers in Coal Mines, 1938-39; Commissioner C'wealth Board of Inquiry into Coal Industry 1945-46. B. Mudgee, NSW, 18 Nov 1878. Died 8 Jul 1954.

[4] Mr Justice Davidson, "History and Status of Industrial Relations and Welfare Work", *Coal in Australia*, p. 523.

tion of coal stocks, took the decisive step of setting up the Commonwealth Coal Board,[5] empowering it to control the supply, distribution, storage and use of coal and to do all things necessary to achieve these objectives. In the following August the Government decided to entrust these powers (now extended to include production, treatment, handling and marketing) to one man, designated the Commonwealth Coal Commissioner. To this onerous and highly responsible position Mr Mighell[6] was appointed, with Mr McKensey[7] as Production Manager, Mr Leman Williams[8] as Distribution Manager, and Mr Jack[9] as Chief Executive Officer. All had had extensive experience in the coal industry. The commissioner was given no power in respect of matters relating to health or safety in coal mines, nor did he, although charged with the responsibility of maintaining production, originally have power to intervene in industrial disputes, which were the cause of great losses in production throughout the whole period of control.[1] Until October 1941 there were three different instrumentalities endeavouring to control the production of coal in one respect or another: the Coal Commissioner, the Central Reference Board (industrial disputes), and the Mines Department of New South Wales (health and safety). In these circumstances some confusion and indecision were almost bound to arise.[2]

With the change of government in October 1941, when the Curtin (Labour) Government came into power, the Miners' Federation, which had always opposed the appointment of a single commissioner, was reconciled to some extent by the appointment of the Commonwealth Coal Commission. For Mighell this meant little more than a change in designation, since he became chairman of the new commission.[3]

In March 1944 the last of the major wartime changes of administration was made: the commission was abolished and once more a single Commonwealth Coal Commissioner was appointed—a post again filled by Mighell.

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[5] Statutory Rules 1941 No. 33—Coal Control Regulations. Personnel: Mr Justice Davidson, Supreme Court of NSW, Chairman; Hon T. Armstrong, MLC, Chairman of Directors of J. & A. Brown & Abermain Seaham Collieries Ltd; C. Nelson, Aust Coal & Shale Employees' Federation; A. G. Denniss, Chief Traffic Manager, NSW Railways; S. B. McKensey, Superintendent, Hebburn Collieries Ltd; W. H. Tucker, Dept of Supply & Development; E. McCarthy, Dept of Commerce.

[6] Sir Norman Mighell, CMG. (Served 1st AIF.) Solicitor and barrister; Chrmn Repat Commssn 1935-41; C'wealth Coal Commssr 1941-46; Dep High Commssr for Aust in Great Britain 1946-50; Dir Zinc Corp 1950-55. B. Mackay, Qld, 12 Jun 1894. Died 13 Apr 1955.

[7] S. B. McKensey. Colliery Superintendent, Hebburn Collieries Ltd, B.H.P. Collieries Pty Ltd, and Metropolitan Coal Co Pty Ltd; Member C'wealth Coal Board 1941; Production Manager C'wealth Coal Commission 1941. Of Weston, NSW; b. Newcastle, NSW, 22 Aug 1889.

[8] H. Leman Williams. Managing Director, Brown's Coal Pty Ltd, Melb, 1931; Distribution Manager to C'wealth Coal Commissioner 1941-46; C'wealth Coal Commssr 1946-47; Director and Manager, Cessnock Collieries Ltd, since 1947. B. Wallsend, NSW, 8 Feb 1897.

[9] R. P. Jack. Inspector then Senior Inspector of Collieries, NSW, 1925-41; Executive Officer and Production Manager, C'wealth Coal Commission, 1941-47. Of Maitland, NSW; b. Scotland, 30 Aug 1898. Died 8 Aug 1950.

[1] Safety of operations of coal mines was governed by *Coal Mines Regulations Act 1912-44 (NSW)*, which was a remarkably good piece of legislation for this purpose.

[2] This state of affairs persisted until, after a general strike of all fields in the southern districts of NSW, the *Coal Production Act* of 1944 was passed and some small improvement was effected.

[3] The other members were: Hon T. Armstrong, representing the mine owners, and B. Cunningham, representing the Miners' Federation (replaced after a ballot by W. Orr).

The Production Branch of the Coal Commissioner's administration comprised technical men of wide experience who were able to visit mines and advise on the manner in which a mine should be operated for maximum output. It was not considered necessary to build up a large technical staff for this purpose since the prevailing opinion was that the major difficulties affecting output, in New South Wales especially, were industrial rather than technical.

Attempts to increase the rate of production of coal centred mainly on extending the application of mechanical methods already in use. Several unavoidable natural trends operated to limit the hoped-for improvements. The efficiency of coal production in a mine inevitably declined as the workings were continually pushed further from the mine entrance, since this necessitated a shorter working period at the coal face for each miner and more labour to transport coal from the face to the mine entrance. Thus efficiency might fall in spite of the increasing use of mechanical methods of coal winning, and this is substantially what happened over the war years. Mechanisation was confined mainly to the mines under the control of the Broken Hill Proprietary Company Ltd and Australian Iron and Steel Ltd, where it was possible only because these companies were able to manufacture the necessary mechanical equipment: cutters, loaders and locomotives. Coal-cutting machinery was not imported during the war.

This commendable effort at local self-sufficiency, which made these mines among the most efficiently run in the Commonwealth, was not, however, enough to offset the results of the natural trends described above and industrial opposition to the use of mechanical equipment. In 1939 1,100,000 tons of black coal or 9.8 per cent of the New South Wales output was mechanically loaded, and 3,594,000 tons or 31.1 per cent mechanically cut; by 1944 these figures had risen to 2,200,000 or 20 per cent and 4,000,000 or 37 per cent respectively. Despite the increase in use of mechanical equipment and the upsurge of production in 1941-2, the efficiency of the industry as a whole, when measured in terms of the output per man-shift, fell from 3.5 in 1938 to 3.3 in 1941, and thence to 3.1 in 1944.

Some of the fall in the rate of output arose from the necessity of working inferior deposits, and some of it was due to industrial unrest. Miners frequently opposed the introduction of mechanisation in the mistaken belief that it tended to make mining more dangerous. As Davidson pointed out: "Increased mechanisation alone will not increase production. It must be accompanied by the will to use to their full capacity the machines that are installed."[4] To which could be added: there must be a proper understanding of the uses to which different kinds of machine can be put. Some of the disappointing results of mechanisation in Britain were due to the fact that too much attention was paid to mechanising coal cutting

[4] Report of the Davidson Commission (1946), p. 86.

and not enough to haulage, with the result that output at the working face was limited to what the haulage facilities could handle.

Efforts to increase underground coal production having met with little success, attention was next turned to the possibility of open-cut mining. This method, which under the same stimulus was being increasingly exploited in Britain and the United States, was not entirely new to Australia —it had long been used for brown coal, but except on a very small scale it had not been applied to black coal.

In May 1944 the Commonwealth Coal Commissioner took control of Commonwealth No. 2 Open Cut Mine at Lidsdale, which at that time was working on a small output ranging from about 50,000 to 60,000 tons a year. The mine was being worked with two obsolete steam shovels nearing the end of their usefulness, and the increasing thickness of overburden portended an effective life of only a few more months. In the face of considerable difficulty the commission managed to obtain sufficient new equipment to replace the worn-out shovels, and by the end of the year output was doubled. The most important development of open-cut mining in New South Wales took place at Muswellbrook, where on an area situated between two underground mines drilling had revealed the existence of a 13-foot seam of excellent coal at a depth of 42 feet, and a still deeper seam 28 to 30 feet thick. Open-cut mining began in November 1944 and by the end of December of the same year the first coal was produced.

In Western Australia, on the advice of the Coal Commissioner's technical officers, a highly successful open-cut mine was developed on the Collie field, which did much to offset losses of production from other mines in that area. Open-cut mining in the regions of Callide and Blair Athol, in Queensland, where there were very large deposits workable by this method, was only just beginning as the war came to an end.

A wartime development interesting not so much for the value of the coal obtained (which was small) as for its later possibilities, was the opening up of the Leigh Creek coalfield, 377 miles from Adelaide—the first coal to be mined in South Australia.[5] Leigh Creek coal was a black, low-rank, hydrous coal, containing 30 to 40 per cent of water in its raw state, with a calorific value of about 6,000 B.T.U. per pound (as compared with 13,000 B.T.U. for New South Wales gas coal and 3,000 to 4,000 B.T.U. for Victorian raw brown coal). Like all hydrous coals Leigh Creek coal disintegrated on drying in air, and because of its tendency, when in this condition, to undergo spontaneous combustion, was somewhat difficult to handle. In spite of all its disadvantages, the increasing difficulty of obtaining shipping space and the growing demands of the munitions program focused interest on the Leigh Creek coal. Development of this coalfield owed much to public interest and a determination to avoid the dislocation of industry caused by interruption of coal supplies from

[5] S. B. Dickinson, "Leigh Creek Coalfield", *Coal in Australia*, p. 645.

New South Wales. Leigh Creek's main advantage lay in providing fuel for the generation of electric power. However, South Australia remained dependent on imported coal and coke for gas works and the iron and steel industry.

The amount and proportion of black coal mined in New South Wales by open-cut methods during the war is shown in the accompanying table.

The quantities and proportions of coal mined in NSW mechanically and by open-cut methods

Year	Total output incl. open cut mines (tons)	Output of underground mines (tons)	Underground coal mechanically filled (tons)	Percentage mechanically filled underground	Output of open cut mines (tons)	Percentage of open cut to total output
1938	9,570,930	9,531,000	619,491	6.47	—	—
1939	11,195,832	11,149,000	1,101,392	9.84	—	—
1940	9,550,098	9,465,000	1,332,099	13.95	45,000	0.47
1941	11,765,698	11,649,000	2,142,420	18.21	67,000	0.57
1942	12,236,219	12,149,000	2,585,035	21.11	57,000	0.47
1943	11,528,893	11,414,000	2,514,114	21.81	60,000	0.52
1944	11,102,138	10,863,000	2,229,899	20.08	180,000	1.62
1945	10,237,886	9,653,000	2,168,184	21.18	523,000	5.11
1946	11,216,535	10,430,000	2,494,785	22.24	756,000	6.74

Source: Joint Coal Board.

By far the most important open-cut mine in the Commonwealth was situated at Yallourn, Victoria, on one of the largest known deposits of brown coal. Yallourn coal was still lower in rank and higher in moisture content than that at Leigh Creek and Collie, and unless burned in specially-designed grates had to be briquetted before use. Dried in the ordinary way, brown coal disintegrated and became especially liable to spontaneous combustion; handling and storing were therefore kept to a minimum.[6]

The first successful attempts to mine and use brown coal for steam raising and the generation of electrical power, were launched largely as a result of industrial troubles in New South Wales in the first world war. Acting on the advice of the Brown Coal Committee, the Victorian Government in 1918 passed the State *Electricity Act* which provided for the establishment of an electrical power industry based on brown coal and the setting up of a commission to administer the new industry. Under its first full-time chairman, General Sir John Monash,[7] a great organiser and administrator in peace as well as in war, the State Electricity Commission forged ahead with its plans and by June 1924 electrical power derived from raw brown coal was being supplied from Yallourn to the city of Melbourne. In the meantime, as a result of investigations carried

[6] Manifestation of spontaneous combustion is not confined to hydrous coals. It may occur, though not so readily with black coals such as those of the Greta seam (NSW). See L. F. D. Cane, "Spontaneous Combustion", *Coal in Australia*, p. 287.

[7] General Sir John Monash, GCMG, KCB, VD; BA, DCL, LLD, DEng. Commanded 4th Aust Infantry Brigade, 1914-16, 3rd Aust Division 1916-18, Aust Corps 1918; Chairman of Commissioners and General Manager, State Electricity Commission of Victoria, 1919-31. Of Melbourne; b. Flagstaff Hill, Vic, 27 Jun 1865. Died 8 Oct 1931.

out at the University of Melbourne by Dr Herman[8] and some time later in Germany, where brown coal had been exploited on a large scale for many years, the commission successfully developed the briquetting of brown coal. Briquetting consisted of crushing, screening (sieving), drying (at about 150 degrees Fahrenheit), cooling and compressing the dried powder under a pressure of 8 to 10 tons per square inch, from which it emerged as a hard, shiny block, almost black, with a moisture content of about 15 per cent and a calorific value approximately three times that of the raw coal.

Much of the machinery used in briquetting was imported from Germany, but during the war when it could no longer be obtained from this source it was made locally. At first the use of briquettes was confined to domestic heating; subsequently as they became available in greater quantities and the desire to replace New South Wales coal increased, the industrial market overtook and exceeded domestic sales.

Experience in Europe showed that burning raw brown coal in equipment especially designed for it presented little difficulty, but adaptation of grates designed in the first instance to use black (bituminous) coal necessitated considerable experimental work. This work was carried out by the commission's Fuel Economy branch. Similar methods of adaptation had proved successful in the conversion of industrial plant to the use of the high-ash, high-moisture, sub-bituminous coal of Leigh Creek. It was shown that different types of installation could be adapted to give the full rated output when using raw brown coal of 50 per cent moisture content.[9]

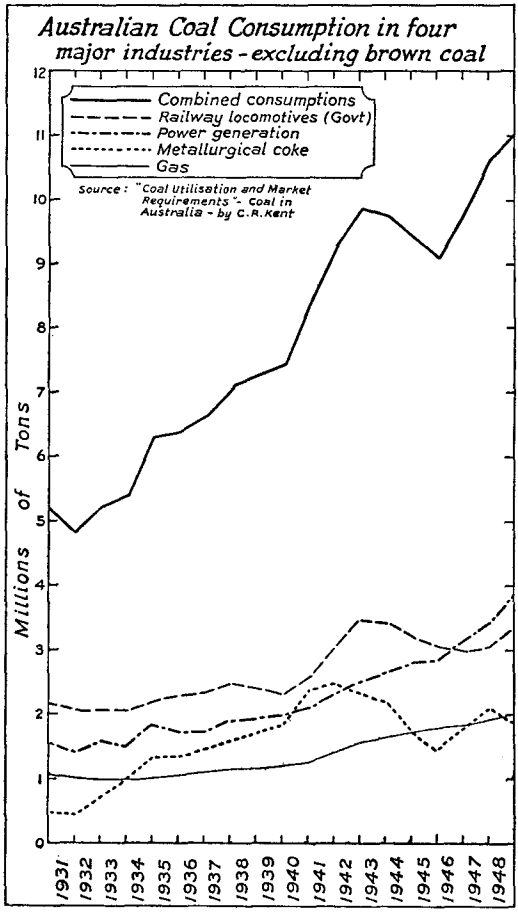
By 1939 briquettes were being produced at the rate of 400,000 tons a year—an output which required about 1,500,000 tons of raw coal. Throughout the war the Yallourn briquetting works operated twenty-four hours a day, seven days a week, increasing production at the peak to 430,000 tons a year. When, as a result of the increased demands of the war industries and the growing difficulty of sea transport, Victoria became acutely short of black coal, the whole output of briquettes from Yallourn was diverted to industry. This was not the only way in which Yallourn helped to meet the war industries' demands for power. The output of raw brown coal was raised from 3,064,000 tons in 1938-39 to 4,588,000 tons in 1943-44. New cuts were opened up and extra machinery, much of it second hand, was put to work to provide brown coal for industries which had previously used black coal or briquettes.

On the whole the distribution of coal during the war was equitable and well-organised, a fortunate circumstance which can be attributed

[8] H. Herman, DSc, MME, BCE. Chairman State Advisory Ctee on brown coal, Vic, 1917; Engineer-in-charge Briquetting and Research, Vic State Electricity Commission, 1920-40, Consulting Engineer since 1940. B. Bendigo, Vic, 16 Aug 1875.

[9] *Reports on Fuel Economy since 1939*. Aust National Ctee, Central Office of the World Power Conference, London. See also I. McC. Stewart, J. R. Nicholson and H. P. Reinbach, "Use of Raw Brown Coal on Industrial Stokers"; Section C2, Paper No. 15, Fuel Economy Conference of the World Power Conference, The Hague (1947).

largely to the fact that Mr Williams, distribution manager for the Coal Commission, was not only familiar with the coal trade in all States of the Commonwealth but had a wide knowledge of the uses to which the different types of coal could be put. A particular type of coal which came chiefly from Maitland, New South Wales, was needed for gas making; no other Australian coal was so well suited to this purpose. Other types of coal were used for steam raising, or for making metallurgical coke, and it was essential, if coal was to be used efficiently and economically, that each type should be kept for the purpose to which it was best suited. Distribution in the different States was made through Coal Control Committees, each under the direction of the distribution manager. Throughout the war these State committees functioned in an honorary capacity and did excellent work; they rationed distribution within their respective States of available coal and advised the Coal Commissioner fortnightly of stocks and demands in all industries. The New South Wales Committee, comprising representatives from shipping, railing and coal interests, did a great deal of work at Newcastle allotting the available coal to ships nominated to carry it. This key committee was given very wide powers: to avoid delays in shipping it could requisition coal from any colliery for shipment interstate; to avoid delays in collieries, caused by lack of waggons, it could requisition privately-owned rolling stock. These powers were very frequently exercised.



At the beginning of the war substantial reserves of coal were held in all States. Nevertheless, in the belief that production might outstrip requirements and that difficulties might arise in finding sufficient shipping, the Commonwealth Coal Board decided to build additional dumps of coal for

emergencies at Port Waratah, Dubbo and Cootamundra (all in New South Wales). Unfortunately the board's optimism was not justified. There was never at any time during the war enough coal to permit the building up of stocks, and these sites, with all the equipment that had been installed in anticipation of surplus supplies, were gradually disposed of to the New South Wales Government Railways. When there were not enough Australian-owned vessels for sending coal from New South Wales to other States, oversea vessels and the railways were pressed into service. At one stage of the war coal was sent by rail from Lithgow to Melbourne and from Muswellbrook to South Australia.

Throughout the war one of the main problems was to coordinate supplies of coal with movement of ships: often when there was plenty of shipping available there was no coal because of strikes; conversely, there were times when production was at a high level and no ships were available to carry the coal interstate. This meant that ships were sometimes filled with coal regardless of quality with the result that some of the carrying capacity of the limited shipping available was wasted.

Economy in the use of fuel became of particular importance as the war progressed and pressure on supplies increased. Although the larger industrial firms maintained permanent technical staffs whose business it was to obtain maximum efficiency in the use of fuel, and State railways ran special sections concerned with the efficient operation of locomotives, there was still much room for improvement among the numerous smaller consumers. In the hope of achieving this, the Commonwealth Coal Commission appointed Mr Stewart[1] Fuel Economy Engineer early in 1943. A staff of technical officers under his direction, with the voluntary collaboration of a number of engineers in the different States, visited several hundred industrial plants to advise on measures of fuel economy, the use of alternative fuels, or on the difficulties arising from changed coal supplies. They also arranged lectures on fuel economy at the technical colleges in Melbourne, Sydney and Brisbane, and published pamphlets on fuel economy in various industries.

Such economies as were effected failed to overcome the chronic wartime shortages, with the result that the reserves of coal built up before the war were slowly exhausted and the continuous operation of public utilities and essential industries was seriously threatened. However no munitions factory was ever forced to stop because of a lack of coal. Restrictions on the use of coal for non-essential purposes were imposed and were particularly severe in Victoria and South Australia. For a brief period lasting from the onset of the German attack on Russia until Australia appeared to be safe from invasion by the Japanese, industrial disputes were laid aside and production rose to an all-time, though not very impressive, record. Thereafter, in spite of all that could be done, it

[1] I. McC. Stewart, ME, SM. Engineer, City Electric Light, Brisbane, 1937-39; Research and Design Engineer for Dehydrated Foodstuffs, Dept of Commerce, 1940-43; Fuel Economy Engineer, C'wealth Coal Commission, 1943-49. Of Brisbane; b. Brisbane, 17 Oct 1912.

fell steadily for the remainder of the war, as may be seen from the accompanying table.

Australian production of black coal

Year	Output	No. employed
1938 . .	11,680,000 tons	20,666
1939 . .	13,535,000 „	21,562
1940 . .	11,726,000 „	22,323
1941 . .	14,212,000 „	22,546
1942 . .	14,903,000 „	22,250
1943 . .	14,193,000 „	22,714
1944 . .	13,697,000 „	22,890
1945 . .	12,792,000 „	22,648

One effect of the war was to increase production of coal outside the main areas in New South Wales; the extent of this is best illustrated by some comparative figures, as given in the accompanying table. The table does not include figures for brown coal, which would accentuate the trend considerably.

Production of black coal in N.S.W. and Australia—comparative figures

Year	NSW tons	Aust tons	Difference tons	Percentage of total prod. outside NSW
1939 .	11,196,000	13,535,000	2,339,000	17.3
1940 .	9,550,000	11,726,000	2,176,000	18.6
1941 .	11,766,000	14,212,000	2,446,000	17.2
1942 .	12,236,000	14,903,000	2,667,000	17.9
1943 .	11,529,000	14,193,000	2,664,000	18.7
1944 .	11,102,000	13,756,000	2,654,000	19.3
1945 .	10,238,000	12,793,000	2,555,000	20.0

By the end of the war Queensland was for all practical purposes self-supporting: for some years before the war her imports of New South Wales coal had been very small, and by 1945 the only consumers were gas companies in the far north. Western Australia had an abundance of coal for its own needs, but because it was of a kind not suited to gas making, limited quantities of New South Wales coal were still required for gas works. Tasmania's importations were confined to coal for gas-making. Victoria, though still using about 1,500,000 tons of New South Wales coal each year, was, as already mentioned, vigorously pursuing a policy of developing the production and use of brown coal with the ultimate aim of making herself independent of New South Wales. For Australia as a whole the States' growing independence of New South Wales coal was a good thing, but it was not without grave threat to the future of the New South Wales coal industry.

That dust in coal mines had a harmful effect on the health of the miner does not appear to have been fully recognised until quite recently. In the early thirties eminent medical authorities were divided in their opinion on the subject, some even holding the view that dust was beneficial. As more reliable methods of diagnosis became available, the menace of dust to health was slowly exposed. There was a divergence of medical opinion upon the exact causes of pneumoconiosis (an omnibus name for diseases of the respiratory system caused by inhalation of dust); it was not known whether the disease was caused by siliceous dusts or by dusts from coal itself. One thing appeared certain: pneumoconiosis was caused by dust. Until this had been established there was little incentive to reduce the amount of dust in mines. During the war the attack on the dust menace was renewed and sustained.

Although coal mines in the regions to the north, west and south of Sydney all operated on coal seams belonging to the same geological series, the incidence of dust in different mines varied greatly: mines in the southern district were as a rule very dusty; those in the Newcastle area were less so, while in the mines of the western district there was very little dust. The first experiments in Australia on the infusion of coal *in situ* with water for the purpose of preventing the formation of dust were made in 1939 at the Metropolitan Colliery (New South Wales) by the Superintendent, Mr McKensey. Experiments along the same lines were tried in neighbouring collieries but all were temporarily abandoned.

Almost immediately after the passing of the *Coal Production (Wartime) Act* in March 1944, the commissioner took over control of the Coal Cliff Colliery, in the southern district of New South Wales. Every conceivable practical step was taken by the commissioner's staff to improve the working conditions at Coal Cliff—foremost being measures to combat dust. Ventilation of the coal-face workings was substantially improved and water was reticulated into every working face for use by miners in allaying extraneous dust, though miners intent on maximum output and maximum wages often ignored instructions to use this water.[2] Systematic measures taken to prevent fine particles of dust formed by the breakage of coal during mining operations—infusion of water into the solid pillars of coal by way of boreholes, and the laying of dust on roadways by means of water or deliquescent salts—went a long way towards achieving their objective.

Work on the hazards of coal dust was not the only attempt made at this time to improve the working conditions in coal mines. General problems of health and safety in coal mines had been exhaustively examined by a Royal Commission in 1938 and many of its recommendations were introduced by legislation in 1941. Health and safety rules were again

[2] F. M. Jefferson (Manager of Coal Cliff Collieries), "A Brief Review of the Measures for the Suppression of Dust in N.S.W. Coal Mines", *Coal in Australia* (1953), p. 454. Infusion of water into the solid coal face was not a new idea at the time of the Coal Cliff experiments. It had in fact first been tried in South Wales; its first use in New South Wales was at the Metropolitan Colliery on the South Coast of NSW in 1939. The next record of its application was in South Wales in 1942, where it was introduced to long wall faces. At Coal Cliff in 1944 it was used for the first time in pillar workings.

revised and brought up to date by a Royal Commission sitting in 1945, with the result that Mr Justice Davidson could write: "It must be acknowledged consequently that there are today no more stringent and complete provisions in that behalf in any part of the world than exist in this State (New South Wales)."[3]

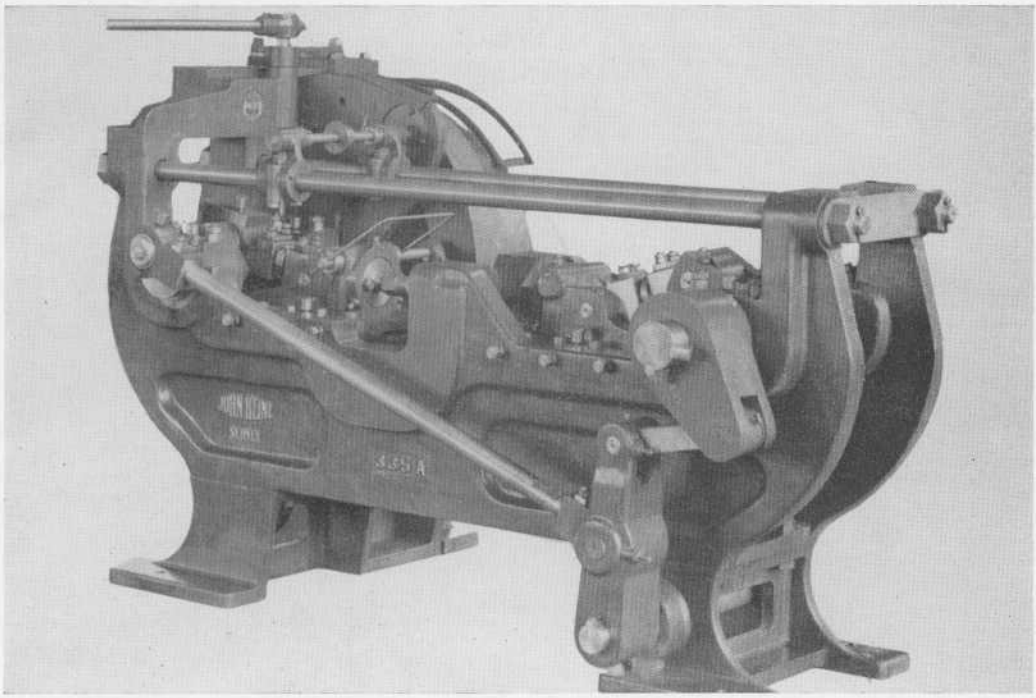
OIL

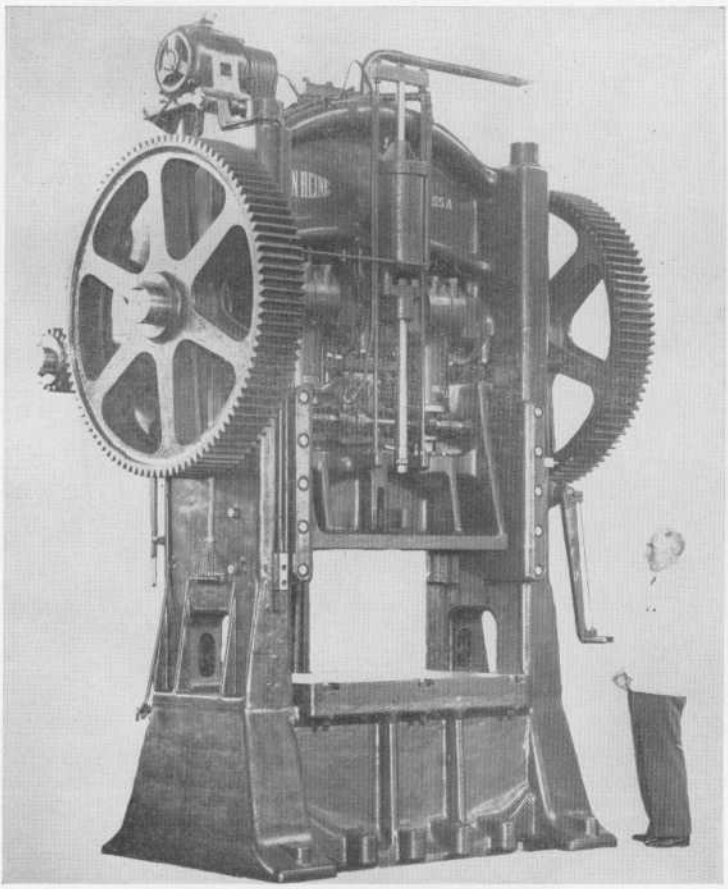
Up till the end of the second world war no flow oil of any consequence had been discovered in Australia. Complete dependence on imported supplies of oil was one of the serious weaknesses in the material basis of Australian defence, and one for which there was no satisfactory remedy except storage of large quantities for emergency. Early in 1940 the Department of Supply and Development arranged with Australian oil companies that they should voluntarily build up the stocks of petroleum products—particularly motor spirit—to a level as high as six months' requirements, and hold them at that level as far as circumstances would permit. They failed to achieve this objective, not because of any unwillingness on their part but because of the operation of oversea controls on distribution of supplies from refineries and on the movements of tankers.

In August 1940 the Commonwealth Oil Board was constituted for the purpose of collating and examining all questions relating to stocks and supplies of liquid fuels and aviation spirit, and for the purpose of formulating plans for supplying these commodities to the armed services and to civilians. With the aim of keeping civilian consumption of petroleum products down to the bare minimum for essential services, the Government, on the board's recommendation, introduced petrol rationing in October 1940.

The only two refineries operating in Australia at the outbreak of war were the Shell Company of Australia's plant at Clyde, New South Wales, and that of the Commonwealth Oil Refinery at Laverton, Victoria. Between them they possessed the capacity for refining about 20 per cent of the petroleum products consumed in Australia in peace time. Both plants were closed for most of the war: the Shell Refinery from February 1942 (after Borneo, whence it drew its supplies, fell to the Japanese) to March 1946, and the C.O.R. from March 1942 to November 1946. Another reason for the inactivity of these refineries was that there was, in Allied countries, a much greater shortage of crude oil tankers than of refining capacity. For this reason the Commonwealth Oil Board took the view that the substantial storage tanks at the local refineries would be better employed for holding refined rather than crude oil. The Commonwealth Oil Board was the first of the coordinating and regulating boards set up for the purpose of ensuring adequate supplies of liquid fuels for the armed forces and essential civil requirements. It was followed some two years later (in August 1942) by the Allied Petroleum Products Estimating Committee which, at the request of General MacArthur's headquarters,

[3] Report of the Royal Commission (Mr Justice Davidson, Messrs S. B. McKensey and F. Lowden) appointed to inquire into and report upon the Safety and Health of Workers in Coal Mines.





A special press known as an indenting machine, which formed the small recess in the end of the .303 cartridge case into which the primer cap fitted.

100-ton 24-inch stroke shell drawing press designed and manufactured by John Heine & Son to draw the cartridge case for the 25-pounder ammunition.



(*Ruwolts*)

The standard 25-pounder with the first short 25-pounder.



(*Australian War Memorial*)

The short 25-pounder in New Guinea.

was set up soon after the arrival of American forces in Australia, for the purpose of coordinating the fuel requirements of the Australian and American armed services. This was a very important committee as far as the Services were concerned, because it provided a focal point at which technical problems relating to the supply of petroleum products could be discussed and resolved. This committee, under the chairmanship of Mr Tucker,[4] did more than prepare estimates of requirements; it sponsored the construction of a large number of bulk storage tanks at locations round the northern coast of Australia from Exmouth Gulf in the west to Cairns in the east, as well as at Port Moresby and Milne Bay in Papua. The construction of the unusually large reinforced concrete tanks for this program was pioneered by the Metropolitan Water, Sewerage and Drainage Board of Sydney. The first and largest, with a capacity of 27,000 tons, was built at Woolloomooloo (Sydney) to hold furnace oil for the navy. At the time it was not known how the penetration of the oil through the thin walls would affect the strength of the binding between steel and concrete, and for a time there was some anxiety on the part of the constructing engineers whether the tanks would hold the oil. In the event they proved highly successful.

Under the National Security Regulations[5] all the oil companies in Australia formed themselves into one large company known as Pool Petroleum Pty Ltd, for the purpose of handling the sale and distribution of all petroleum products. In this way the most effective use was made of seaboard and inland storage, and economies in distribution were effected that would have been impossible under the competitive system. Efforts had been made before the war to discover how dependence on imported fuels could be reduced by means of indigenous substitute motor fuels. The whole question of these fuels, which it was recognised from the outset could make only a small contribution to Australia's requirements, was thoroughly investigated by the Commonwealth Standing Committee on Liquid Fuels set up in September 1938.[6] The committee made eight reports, covering benzole, power alcohol, shale oil, producer gas, oil from coal, compressed gas, tar fuel and the reclamation of used lubricating oils.

One of the most promising of the substitute fuels was benzene (benzole), a by-product of coke ovens and town gas works. Between them the steelworks of the B.H.P. at Newcastle and Australian Iron and Steel at Port Kembla produced nearly 3,000,000 gallons of benzole a year. A potential supply of a further 3,000,000 gallons a year existed in the different metropolitan gas works, but this could only be tapped at the expense of the calorific power of gas. For the first years of the war benzole was admixed with petrol and used as a motor spirit, but it was really too

[4] W. H. Tucker. (Served 1st AIF.) Superintendent of Stores and Transport 1936-38; Chairman and Controller Liquid Fuel Board, Chairman C'wealth Oil Board 1940-48; C'wealth Public Service Inspector for Vic 1947-53. B. Collingwood, Vic, 9 May 1892.

[5] Statutory Regulations 343 (1942).

[6] Members of the committee were: P. C. Holmes Hunt (Colonial Gas Association Ltd), chairman, E. A. Box (of Sydney), K. Butler (Assistant Manager, BHP Ltd, Newcastle), Dr R. W. Harman (Colonial Sugar Refining Co), Sir David Rivett (CSIR), A. E. Dawkins (Munitions Supply Laboratories), L. J. Rogers (C'wealth Fuel Adviser). Secretary: A. C. Smith.

valuable a raw material to be used in this way. Except for a small amount required by chemical industry the whole of the steelworks' output of benzole from 1942 onwards was shipped to the United States, where it was used in the production of cumene, a component of high-octane aviation petrol.

A considerable amount of effort was put into designing gas-producer units (some 56,000 of which were fitted to motor cars and trucks) and to exploring methods of making charcoal suitable for these units. Although the petrol saved by the use of gas producers was only 1 per cent of the total peacetime consumption, it was quite worth while when measured against the substantially reduced wartime civil consumption. Of greater significance than the actual saving of petrol was the fact that gas producers would have kept mobile the essential commercial transport fleets had Australia been completely cut off from oversea supplies of petrol and forced to rely on her reserves for military purposes.

Following the discovery and development in Germany of methods for producing oils from coal, such as the Bergius high-pressure hydrogenation and the Fischer-Tropsch processes, an inquiry was instituted into the possibility of developing these methods in Australia. A careful examination of both processes did not lead to decisive evidence in favour of either; neither had even the remotest chance of competing economically with natural oil.[7] Nowhere in the world had this been found possible. Germany, then the greatest producer of synthetic oil, was actuated almost entirely by considerations of self-sufficiency. The Australian Liquid Fuels Committee took the view that oil could be stored in anticipation of an emergency much more cheaply than it could be synthesised from coal during an emergency. Before the Fischer-Tropsch synthesis, which to some experts appeared to be technically the more attractive of the two processes, could be introduced into Australia, it would have been necessary to get assistance from German technologists.

In the light of these arguments it can readily be understood that no steps were taken to establish an oil-from-coal industry. The prospects of success were so poor that a special committee of inquiry set up towards the end of the war could report "no logical justification . . . for engaging in research work on the actual synthesis of oil fuels".[8]

National Oil Pty Ltd, in which the Commonwealth and New South Wales Governments and the company held £334,000, £166,000 and £166,000 debentures respectively, was formed in July 1937 with the object of putting the shale oil industry on its feet. Work started at Glen Davis, New South Wales, a year later, and spurred on by the imminence of war the company began producing oil by January 1940, but only at the expense of subsequent efficiency. The retorting plant was still in an

[7] Sir David Rivett, "Oil Production from Coal Viewed from an Australian Standpoint". *Parliamentary Paper No. 71*, Nov 1936.

[8] Report of the Committee of Inquiry on Coal Utilisation Research, CSIR, May 1946: "Production of Oil from Coal", by L. J. Rogers.

untried stage and was found to need considerable modification.[9] In 1940, when it was evident that this could be done only by a large increase in capital expenditure, the Commonwealth Government willingly underwrote an overdraft of up to £250,000 on the Commonwealth Bank.

Attempts to extend the industry, dogged by misfortunes in the form of shortages of experienced technical men and of materials, were not completed until after the war. Nevertheless by 1943 a small but completely modern, highly efficient cracking and refining plant was producing motor spirit at the rate of 1,737,748 gallons a year. Generally speaking, the war years were spent in acquiring the technical data essential for the production of oil from shale, and the value of the industry was believed to be in the future. The Glen Davis project was forced ahead more as an insurance against the possible interruption of the supplies of imported oil than as a result of sound technical judgment. Even at full production its potential contribution of 10,000,000 gallons a year was less than 3 per cent of Australia's fuel requirements. The industry did not long survive the war. Production of motor spirit from this source proved to be uneconomic owing to the high cost of labour, and the reserves of shale simply did not warrant sinking further capital into the industry, which was closed down in May 1952.

The most determined effort to build up supplies of liquid fuels from indigenous materials during the war was by means of a scheme to increase the production of alcohol. In August 1940 the Federal Cabinet set up a Power Alcohol Committee of Inquiry to investigate and report upon the costs and methods of using farm and forest products and by-products for the production of power alcohol.[1] Special attention was to be paid to the wheat and sugar industries as sources of raw material.

The committee recommended that immediate action should be taken to erect distilleries capable of producing 40,500,000 gallons of anhydrous alcohol a year from wheat and cane products;[2] that the selling price of power alcohol, wholesale at capital cities, should be 2s a gallon; that the distilleries should be owned by the Commonwealth with or without the participation of State governments and, or, private interests; that there should be legislation to control the blending of alcohol with petrol and the sale of the blend.

The most satisfactory form of alcohol for internal combustion engines was the absolute, or anhydrous form containing 99.8 to 99.9 per cent of alcohol. Blended with second-grade petrol this formed a fuel of high anti-knock value which could be used in motor vehicles with little alteration

[9] R. F. Cane, "Some Thermochemical Properties of the Torbanite of the Glen Davis Deposit", *Journal of the Royal Society of NSW*, Vol. 76 (1942), p. 190.

[1] The members of the committee were: Hon A. W. Fadden, Chairman; W. J. Rose (C'wealth Tariff Board), Deputy Chairman; H. McClelland (for primary producers); Prof E. Ashby; Dr R. W. Harman (of CSR Co Ltd, Sydney); R. J. S. Muir (Secretary, Qld Cane Growers' Council); W. R. Jewell (Vic Dept of Agriculture); H. A. Pitt (Treasury); H. A. Dodd (Clerk of Committees, Parliament House, Canberra), Secretary.

[2] This figure was based on a pre-war consumption of petrol amounting to 350,000,000 gallons a year. A 15 per cent blend required 52,000,000 gallons of alcohol, but only 7,000,000 gallons were being produced.

to the engine or accessories. Anhydrous alcohol could be used with petrol in blends containing up to 20 per cent of alcohol, but it could not replace petrol entirely in the ordinary motor vehicle. At the time the committee made its recommendation there was no decisive experimental evidence on the question whether a gallon of petrol-alcohol blend would replace a gallon of petrol; the committee was satisfied that, by and large, it would. The only materials from which alcohol could then be made at a reasonable price were molasses and wheat—potatoes, grapes and apples, for example, were far too expensive. Under conditions specified in the report (wheat 3s 10½d a bushel f.o.r.) it was estimated that alcohol could be produced at 2s a gallon. Anhydrous alcohol was being made from molasses for about the same price, but the amount of raw material available from this source was insufficient to meet the requirements of the industry on the scale then contemplated. Raw sugar itself, which the Colonial Sugar Refining Company used in its distilleries at Pyrmont and Yarraville to supplement molasses, was of course a still more uneconomic starting material. Its use was made possible only by a subsidy from the Commonwealth Government. If wheat was to be used it would first be necessary to convert its content of starch to sugar.[3] The most efficient way of doing this was by the amylo process, which involved the conversion of starch to sugar by the mould *Rhizopus* and the simultaneous fermentation of the sugar with yeast.[4] The amylo process was carefully studied in the research laboratories of the Colonial Sugar Refining Company, and because of its higher efficiency it was finally selected in preference to the malt process in general use. A high yield of alcohol was essential when using so costly a raw material as wheat.

On 18th February 1942 the Commonwealth Government signed an agreement wtih the C.S.R. Company under which the company would erect and operate on behalf of the Commonwealth four distilleries to manufacture anhydrous alcohol from wheat. After much discussion the sites finally selected were: Cowra in New South Wales, Warracknabeal in Victoria, Wallaroo in South Australia and Collie in Western Australia. Each plant was to cost just under £442,000 and to have a rated capacity of 3,000,000 gallons a year. The four plants were completed in due course but only one came into operation. The whole plan miscarried, owing in the first instance to the failure of the wheat crop caused by drought. The only plant to produce alcohol was the one at Cowra, which ran for just long enough (barely 12 months) to prove that the cost of constructing the plant and the cost of producing the alcohol were a little less than had been estimated. By the time wheat harvests had reached their usual abundance, the price of wheat had risen so much that manufacture of alcohol from this source was hopelessly uneconomical and all four distilleries were finally abandoned.

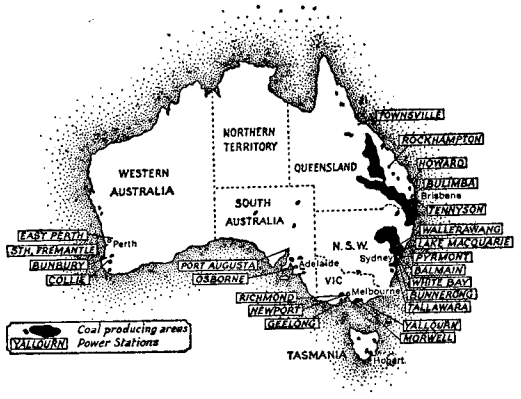
[3] The Scholler process then operating in Germany was able to use wood which had been hydrolysed to sugars by treatment with dilute hydrochloric acid under pressure. The process was not well enough known in Australia for its use to be seriously contemplated during the war.

[4] Based on the age-old practice of the Chinese in making rice wine. Rice is first allowed to go mouldy, when the mould converts the starch to a fermentable sugar.

The end of the war saw the country no nearer independence of outside supplies of motor fuel. Though it was an economic failure the power alcohol project was a technical success in so far as the amylo process had not up to that time been commercially operated in either Britain or the United States.

ELECTRIC POWER

Australia entered the war with a total installed capacity of electric generators in central power stations of 1,718,926 kilowatts, of which 182,052 (slightly less than 11 per cent) were hydro-electric units; the great bulk of the remainder were steam generating units.[5] Their locations—all of them on or within 50 miles of the seaboard—are shown in the accompanying map.[6] Australia's production of electrical power on a population basis is compared with that of several other countries in the accompanying table.



The large number of government munitions factories, the annexes and the far greater number of commercial factories diverted to war production, the camps, airfields, and other Service establishments, transport and communication systems and farms, all needed electrical power. Increased demands for electrical power arose soon after war broke out. However, the main concern at first was with the safety of existing installations.

Production of electricity in 1939-40[7]

Country	Output in millions of kWh			Output in kWh per capita	Population density per sq. mile
	Thermal stations	Hydro-electric stations	Total		
Australia	4,397	783	5,180	733	2.38
Great Britain	29,176	800	29,976	652	521.8
Canada	585	29,524	30,109	2,641	3.3
United States	97,232	47,753	144,985	1,107	44.0

State electricity authorities put into effect plans made soon after the Munich Conference to ensure the protection of their main generating stations and other electrical establishments against possible sabotage, by

[5] Small diesel units were in use in some of the more remote country towns.

[6] Taken from V. J. F. Brain, "Some Observations on the Electricity Supply on the Australian Mainland". Presidential address to 32nd Annual General Meeting of Institution of Engineers, Aust, *Journal of Institution of Engineers*, Vol. 24 (1952), p. 123.

[7] From C. M. Longfield, "The Past, Present and Future of Aust Power Supplies", p. 6. From a pamphlet published by the Economics Society of Aust & N.Z. (1947).

restricting admission to them and by mobilising internal guards. They also began to take the usual precautions against air raids, setting up emergency control rooms and systems of communication to be used in the event of major damage to installations; erecting shelters, duplicating valuable records, and organising fire-watching services. Such measures, applied to the whole of a State generating system, were costly. The State Electricity Commission of Victoria, for example, estimated that it spent approximately £1,000,000 on protective measures of this kind. Supply authorities also made arrangements for the interconnection of major systems and for giving appropriate priority in the event of damage to power stations, to essential services such as telephone exchanges, water pumping, hospitals and munitions factories.[8]

Defence authorities appear to have been slow to recognise the critical importance of organising supplies of electrical power on a national basis. At the time of the great expansion of war industry which followed the setting up of the Department of Munitions in June 1940, the Electricity Supply Association of Australia[9] offered to the Commonwealth Government its facilities and assistance in maintaining the supply of electricity throughout the Commonwealth. The offer was not acknowledged until 31st January 1942 (after Japan had entered the war).[1] On that date the Secretary of the Department of Munitions wrote:

> In view of the recent events it is felt that an immediate survey should be made to ascertain exactly the plant needed for assurance of continuity of supply throughout Australia should any part be affected by enemy action.

The association promptly agreed to undertake this and other investigations suggested by the Department of Munitions, and set up a special committee for the purpose.[2] On the committee's advice the Minister for Labour and National Service declared electricity supply organisations to be protected undertakings under the *National Security Act*—a belated recognition of the importance of power supplies for defence.[3]

It soon became apparent that the defence authorities were not in a position to give effect to the many technical recommendations made by the committee, especially those relating to the coordination of electricity supplies throughout the Commonwealth. A conference called by the Deputy Director-General of Munitions on 27th August 1942 decided that an organisation for the control of electricity supply should be formed and that

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[8] I am indebted to Mr A. H. Cadd of the Electricity Supply Association for assistance in gathering the information upon which the latter half of this chapter is based. Most of the statistical data were provided by his association.

[9] A body formed by electricity supply authorities throughout Australia (government, municipal and private) for the purpose of furthering the national interest through developments in the supply of electricity.

[1] *The Munitions Digest*, June 1945, p. 394, comments: "It has to be realised that electricity supply is the lifeblood of our war effort and that without electricity munitions manufacture, communication, provision of the necessaries of life and other matters could not be maintained on the scale required by the war. It is not clear why failure to realise the importance of electricity in this connection should have arisen, but it is necessary to mention it."

[2] The members were: B. S. Woodfull, City Electrical Engineer, Melbourne; F. W. Wheadon, Managing Director Adelaide Electrical Supply Co Ltd; G. H. McDonald, Asst-Chief Electrical Engineer of Vic Railways.

[3] National Security (Mobilisation of Electricity Supply) Regulations, Statutory Rules 1942 No. 413.

it should be placed in charge of Mr Moss,[4] who was designated Controller of Electricity.[5] Moss assumed responsibility for mobilising and coordinating the generation, transmission and distribution of electricity, and for seeing that generating plant, boilers, switch gear and all equipment incidental to the generation and supply of electrical power was available where it was most needed to ensure maximum effectiveness. Australia was fortunate indeed to have entered the war with generating plant whose reserve capacity was 30 per cent in excess of the maximum demand being made upon it.[6] Just before the outbreak of war the size of a number of generating systems had been doubled. This, together with the ample reserves that had accumulated from conservative operating practice, made it possible for Australia to meet the increased power requirements which marked the first two years of the war.

Most heavy electrical engineering plant—certainly all large generating sets—had to be imported, mainly from the United Kingdom where early in the war manufacture of such sets was restricted to those considered essential for defence. Britain, unlike Australia, was without reserves of installed generating capacity and was therefore only able to help other British Commonwealth countries at the expense of her own requirements of power. All the eastern States of Australia were able to import from the United Kingdom some at least of the generating plant required for defence industries which for strategic and other reasons had been placed within their boundaries. It was arranged that Mr Bate,[7] Power Production Engineer of the State Electricity Commission of Victoria, should go to Britain for the purpose of endeavouring to ensure that Australian requirements were given appropriate priority.

Not all the plant sought in Britain by Australian electricity supply authorities was forthcoming, but enough was obtained to enable authorities to eke out supplies of power so that until the last year of the war at least there was no serious threat of rationing. In common with other public utilities, electricity supply authorities had to sustain heavy and often unpredictable demands in meeting the emergencies of war production, while suffering from the inevitable dislocations of war. They were permitted to increase their generating facilities to an extent sufficient only to meet load without reserve. Such new plant as could be manufactured in Australia was rated as war production by the Department of Munitions and given appropriately high priority.

Victoria. Despite difficulties the commission was able to increase its generator capacity by over 30 per cent—from 311,315 kilowatts in June

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[4] H. P. Moss. Chief Electrical Engineer, Dept of Interior, from 1935; Controller of Electricity Supply, Dept of Munitions, 1942. Of Melbourne; b. 14 May 1883. Died 5 Jan 1954.

[5] Regional controllers appointed to assist him were: S. F. Cochran of the Qld State Electricity Commission; V. J. F. Brain, Dept of Public Works NSW; G. G. Jobbins, Vic State Electricity Commission; R. W. Parsons, Adelaide School of Mines; R. J. Dumas, Director of Public Works, Perth; W. E. Maclean, Hydro-Electric Commission of Tasmania.

[6] Brain.

[7] E. Bate, MC; BScEng. (Served 1st AIF.) From 1936 Chief Engineer Power Production, State Electricity Commission, Vic. Of Melbourne; b. Widnes, Lancs, Eng, 12 Oct 1883.

1939 to 409,715 kilowatts in June 1945. Details of the plant extensions made in Victoria are shown in the accompanying table.

New generating plant installed—Victorian State generating system—June 1939 to June 1945

Year			Installed generator capacity in kW
1939	Newport power station (S.E.C.)		30,000
1940	Ballarat power station (S.E.C.) Plant transferred from Bendigo power station (closed 1937) and reinstalled at Ballarat		1,400
1944	Newport power station (S.E.C.)	18,000	
	Kiewa power station (S.E.C.)	12,000	
		30,000	
	Withdrawn		
	Spencer Street power station (M.C.C.)	5,000	
			25,000
1945	Newport power station (S.E.C.)	30,000	
	Kiewa power station (S.E.C.)	12,000	
			42,000
	Net increase		98,400

The plant built at Newport in 1939 formed part of a major extension planned in 1937 to meet Victoria's needs for electrical power up to 1952. In some instances new generator plant installed in thermal power stations could not be fully used because, owing to war conditions, the corresponding extensions to the boiler plant could not be made.

An increase of more than 60 per cent in the production of electricity at Yallourn (from 697,000,000 kilowatt-hours in 1938-39 to 1,133,000,000 kilowatt-hours in 1944-45) necessitated an increase of 44 per cent in the output of coal from the main Yallourn open cut, production rising from 3,643,000 tons in 1938-39 to 5,249,000 in 1944-45. A detailed analysis of the types of fuel used for the generation of electrical power in Victoria during the war years shows that more than four-fifths of the increase in the production of electricity in these years was obtained by the increased use of brown coal at Yallourn and the use of brown coal briquettes there and at the Melbourne metropolitan stations.

The first power station of the Victorian commission's Kiewa hydro-electric undertaking in the Australian Alps began operating in September 1944. Construction of this station and the accompanying Junction Dam to provide the water storage for its operation was pushed ahead of the original peacetime schedule to meet the demands of wartime industry.

New South Wales. The new capacity installed on the systems of the four major generating authorities in New South Wales amounted to 147,500 kilowatts, made up as shown in the accompanying table.

Year		Installed generator capacity in kW
1939	Bunnerong Power Station (Sydney County Council) .	50,000
1941	Bunnerong Power Station (Sydney County Council) .	50,000
	Port Kembla Power Station (Southern Electricity Supply)	7,500
1942	Ultimo Power Station (Department of Railways) .	20,000
	Zarra Street Power Station (Department of Railways)	20,000
		147,500

Towards the end of the thirties it became evident that the growth of the demand for electrical power in New South Wales justified a substantial increase in the size of individual generating sets. The two 50,000-kilowatt sets for Bunnerong Power Station, which had been ordered before the war and installed in 1939 and 1941 respectively, were then the largest machines in Australia. The large size of these units was mainly responsible for the comparatively healthy position of plant reserves during the war years. Approval was obtained for the manufacture in Britain of a third 50,000-kilowatt turbo-alternator for Bunnerong Power Station to assist in maintaining war production. When this machine was completed, however, the British Government decided to divert it to the Soviet Union. A replacement unit was not commissioned at Bunnerong until 1947.

The four largest organisations responsible for supplying electricity in New South Wales—the Sydney County Council, the Department of Railways, the Southern Electricity Supply, and the Electric Light and Power Supply Corporation—between them generated about 96 per cent of the electricity used for public supply and traction purposes. The remaining 4 per cent was generated mainly by small diesel units in the more remote country towns.

Supply of power to the Captain Cook Graving Dock and to the Explosives and Filling Factory at St Mary's—both wartime constructions—accounted for a good deal of the new load on the New South Wales system. In each instance the supply was carried out by the Sydney County Council.

South Australia. The Adelaide Electric Supply Company Ltd planned to begin work in 1940 on a large power station with a capacity of 180,000 kilowatts, to be known as Osborne B. Although considerable progress had been made on its construction by 1943, the station was not commissioned until after the war. Additional power for war production in South Australia was met by calling on reserves and by the addition of a 12,000-kilowatt turbo-alternator to the Osborne A station in 1942. South Aus-

tralia's principal difficulty was to obtain regular supplies of coal. The coal strikes in New South Wales in 1940 reduced reserves from six months' to two months' supply. This condition of unrelieved uncertainty persisted for most of the remainder of the war; at one period in 1944 there was a reserve of only one week's supply.

Western Australia. The East Perth power station was able to cope with the city's additional wartime load without further extensions. A new station at South Fremantle was planned during the war and orders for machinery were placed, but it was not commissioned until 1951.

Queensland. Of the 72,000-kilowatt generating capacity installed in Queensland during 1939-45, more than half was installed during 1940 at centres ranging from Toowoomba in the south to Cairns in the north and Cloncurry and Charleville in the west. The largest unit added during this period was a 25,000-kilowatt turbo-generator for the City Electric Light Company Ltd, Brisbane, in 1944.

To overcome the difficulties caused by inability to import electric generators, the Queensland State Electricity Commission adopted the policy of using the generating facilities of industrial concerns such as timber and sugar mills to supplement the public supply. This system worked so well that it was retained for a while after the war.

Tasmania. In Tasmania where the whole of the State's requirements came from hydro-electric stations, several important extensions were made. The Hydro-Electric Commission completed and put into service a new power station at Waddamana on the Great Lake system, installed additional generating sets in Tarraleah Power Station and acquired a small power station at Duck Reach near Launceston.[8] At the end of the war the installed capacity in the commission's power stations in Tasmania totalled 160,500 kilowatts, which represented an increase of about 60 per cent on the 1939 capacity. During 1938-39 the average loading on the commission's system was about 509,000,000 kilowatt-hours, of which 400,000,000 were generated for producing copper, zinc, carbide and cement. On account of the increased production of these materials and the power requirements of the newly-established paper industries at Boyer and Burnie, the average loading increased to about 738,000,000 kilowatt-hours during 1944-45, including about 550,000,000 generated for the above purposes. Taking into account power used for producing these materials and that used by annexes and food-processing factories, the commission estimated that about 80 per cent of the energy generated in its system was used for wartime production.

Northern Territory. Before the war the only power stations in the Northern Territory were two small units operated by diesel engines to supply Darwin and Alice Springs. Electricity for military camps was at first supplied by small portable generating sets, but these proved inadequate after the end of 1941; between April and June 1942 the number of Australian troops in the Northern Territory increased from 14,800 to

[8] The power generated in this power station by the Launceston City Council in 1895 was the first hydro-electric power generated in the Commonwealth.

22,000 and in December 1942 was 32,400. In the same period the number of air force men in the Territory was also greatly increased. Settlements such as Adelaide River, Katherine, Tennant Creek, as well as Darwin and Alice Springs, now became important defence centres. Generating plants, acquired by the Commonwealth Government mainly from privately-owned factories engaged in work of little significance for defence, were installed at each of these centres:

Darwin area:	*No. 2 power station	(2,150 kW capacity)
	No. 3 power station	(1,700 kW „)
	Navy workshops	(270 kW „)
Adelaide River:	No. 1 power station	(180 kW capacity)
	No. 2 power station	(310 kW „)
Katherine:	*No. 1 power station	(577 kW „)
	Meat works	(140 kW „)
Tennant Creek:	*No. 1 power station	(40 kW „)
Alice Springs:	*No. 2 power station	(707 kW „)

* Indicates stations retained after the war and adapted for civilian use.

Interconnection of electric systems. Where a number of major electric supply systems operated in proximity to one another, great advantages could be obtained, from the point of view both of defence and of economy and flexibility in operation, by linking the systems into a grid. In the event of an interruption to the supply from one system its function could be taken over by other systems in the grid. Interconnection of systems, especially those in New South Wales, was speeded up by the war. Two power systems in Sydney—the Department of Railways and the Sydney County Council—had been linked for many years. Plans for linking the remaining major systems of New South Wales were made just before the war and in the succeeding six years were carried through to serve the needs of defence—the numerous decentralised government munitions factories and annexes, army and air force camps, and, towards the latter part of the war, the food processing industries. The main transmission lines installed in New South Wales during 1939-45 are shown in the accompanying table.

Main transmission lines installed in NSW during the war

Location	Miles	Voltage	Purpose
Port Kembla—Burrinjuck . .	145	132,000	Interconnector
Cowra—Cowra Power Station .	2.25	66,000	Interconnector
Cowra—Orange . . .	47.20	66,000	Interconnector
*Maitland—Singleton Branxton—Singleton Section .	25.50	66,000	Bulk Supply
*Orange—Dubbo . . .	84.70	66,000	Bulk Supply

Main transmission lines installed in NSW during the war—*continued.*

Location	Miles	Voltage	Purpose
Sydney—Port Kembla . .	49.37	66,000	Interconnector
*Taree—Kempsey . . .	70.00	66,000	Bulk Supply
Wagga—Yanco	74.80	66,000	Interconnector
*Caledonian Collieries Ltd . .	1.5	33,000	Interconnector
Corrimal Coal and Coke Co .	5.3	33,000	Coal Mining
Temora—Barmedman . .	23	22,000	Bulk Supply
Bomaderry—Jervis Bay . .	23	11,000	Naval Establishment
Goulburn—Gunning . . .	14	11,000	Bulk Supply
Rural District Supplies. Cootamundra, Cowra, Gundagai, etc	75	11,000	Mixed farming and grazing

Items marked * were constructed by the N.S.W. Department of Railways and the remainder by the Department of Public Works, N.S.W.

In Victoria a large part of the power system had been interconnected before the war; the additional links constructed during the war are shown in the accompanying table.

Main transmission lines installed in Victoria during the war

From	To	Miles	Voltage	Purpose
Newport	Ballarat	69.0	66,000	Munitions
Richmond terminal station	Brunswick terminal station	5.8	66,000	Interconnection
Newport (Victorian Railways)	Yarraville	1.56	22,000	Interconnection of 25- and 50-cycle supplies by frequency changer
Thomastown	Castlemaine	71.00	66,000	Second circuit—Munitions
Benalla	Mulwala	64.9	66,000	Munitions and Air Force
Wangaratta	Kiewa No. 3 power station	63.6	66,000	Program expansion to carry No. 3 power station output, which was a defence project

In South Australia a transmission line was built from Willunga (near Adelaide) to Rapid Bay, for the purpose of supplying power to the new limestone quarries being developed by the Broken Hill Proprietary Company Ltd; in 1943 a second, 66-kilovolt line, was built from Adelaide to Morgan to supply the four pumping stations to the Morgan-Whyalla pipeline. A frequency changer was provided to permit the interchange of power between the Adelaide Electric Supply Company Ltd and the Municipal Tramways Trust.

Queensland, with its smaller and far more widely dispersed towns, could not hope to connect its systems into one huge network, but several of the main towns were linked together in pairs and some rural areas were opened up by the efforts of the City Electric Light Company. A summary of the development of Queensland's power system in the years 1939-45 is given in the accompanying table.

Principal transmission lines erected in Queensland between 1939 and 1945

Authority	Distance and Voltage	Purpose
City Electric Light Co Ltd (now Southern Electric Authority)	323 miles 33/11 kV	Development of rural areas.
	8 miles 33 kV	Interconnection with Brisbane City Council's Power House.
	80 miles* 33 kV	To provide bulk supply to the system of Toowoomba Electric Light and Power Co Ltd.
Barron Falls Hydro Electricity Board	20 miles 22 kV	Innisfail-Silkwood link.
	25 miles 22 kV	Interconnection between systems of Barron Falls Hydro Board and the Johnstone Shire Council at Innisfail.
Toowoomba Electric Light and Power Co Ltd	55 miles 33 kV	Linking Warwick with main system of supply.
	16 miles 33 kV	Provide supply to Oakey for defence purposes.
Townsville City Council	65 miles 66 kV	Link between Townsville and Home Hill power stations for security of supply for defence purposes.

*110 kV construction energised at 33 kV.

In the early part of the war attention was concentrated mainly on strengthening sources of electric power in the larger centres of population, with the result that little could be done about extending electric supply to farms. Towards the end of the war when emphasis was shifted from production of munitions to food, increasing attention was given to the possibility of extending the electricity supply to regions where it would assist in producing food. Little progress was made in this direction. In New South Wales a few extensions were made in the coastal areas to dairy farms. By the end of the war less than 16,000 farms (that is less than one third of the farms within economical range of public supply mains) were actually connected, and most of these had been connected before the war.

The production of electrical energy between 1939 and 1945, and the contribution of each State to the grand total, are shown in the accompany-

ing table.[9] The general effect of the war was not so much to increase the generation of power as to divert existing supplies into new channels.

Australian production of electric energy, 1939-40 to 1944-45

	Millions of kilowatt-hours					
	1939-40	1940-41	1941-42	1942-43	1943-44	1944-45
N.S.W.	2,146	2,405	2,656	2,844	2,826	2,877
Vic.	1,390	1,550	1,628	1,756	1,758	1,796
Q'land	422	457	481	515	563	602
S. Aust.	270	304	385	418	394	410
W. Aust.	337	354	347	318	313	330
Tasmania	615	670	727	771	802	802
AUSTRALIA	5,180	5,740	6,224	6,622	6,656	6,817

Except for several years during the economic depression there was, up to 1939, a steady annual increase in the consumption of electrical power at an average rate of about 8 per cent. In the early years of the war the rate of increase rose substantially above this figure. After the munitions drive reached its peak in 1943 the rate of increase was very small indeed. There were a number of reasons for this: reserves of generating capacity had been exhausted; practically no domestic appliances were manufactured in this period; and many non-essential industries using electrical power were closed down. Added to all these was the general slackening of the munitions program itself.

[9] From Bulletin No. 32 (1944-45), Commonwealth Bureau of Census and Statistics.

CHAPTER 11

GUNS

UNTIL about the end of 1936 not a single gun in the ordnance category, which excludes machine-guns, had ever been made in Australia. It is true that the first Government Ordnance Factory at Maribyrnong had been planned as early as 1923 and that work on it was begun soon afterwards. By 1928 it was equipped with machinery, much of which had been bought on highly favourable terms from the United Kingdom just after the first world war, and it was ready to make the 18-pounder field gun, which had been adopted in 1904 and had become, in its class, the standard field gun of the British Army. Throughout its existence the policy of the Munitions Supply Board was that Australia should make only the types of gun adopted by the British Army; firstly because there was no point in trying to design guns in a country which had no experience of gun design, and secondly so that British-made and Australian-made guns and ammunition would be completely interchangeable. The techniques of making guns were first learned direct from Britain during 1919-20 when a small group of Australians studied the manufacture of the 18-pounder ordnance and carriage at Woolwich Arsenal. The group included Mr O'Loughlin[1] and Mr Daley, who were to take an active part in organising the manufacture of guns in Australia during the second world war.

Descriptions in full detail of the manufacture of a gun, or for that matter any munition of war, are beyond the scope of this volume. The most that can be done is to deal briefly with a few of the more interesting production processes, and to indicate here and there the obstacles encountered by industry and the way in which scientists and technologists assisted in overcoming them. Since the manufacture of each type of gun followed much the same general course, once the manufacturing details as summarised in working drawings and specifications had been decided upon, it may be helpful, and will certainly save repetition, if some of the more important stages of production are outlined in general terms.

Procurement of raw materials, which for a gun might include some twenty different kinds of steel and almost as many different non-ferrous alloys, was one of the first steps. Simultaneously, machine tools, jigs, gauges and fixtures had either to be designed and built by firms that specialised in such work or, in the early and more dependent phases of industrial development, be obtained from other sources, usually by importation.

Raw materials reached the factory in the form of ingots, plates, bars, sheets or strips which had been forged or rolled to shapes and

[1] M. M. O'Loughlin. Manager, Ordnance Factory, 1937-54; General Manager, C'wealth Govt Ordnance Factories, 1947-54; Controller-General of Munitions Supply 1950-52. Of Melbourne; b. Adelaide, 2 Feb 1887.

sizes as near as practicable to the size and shape of the finished component for which they were intended. All materials were thoroughly tested, chemically and physically, to make sure they conformed to the specifications laid down for them. Then followed operations of forging, pressing, fabricating, or other roughing-out processes whereby the material took a shape more nearly that of the desired component. Heat treatment—annealing, quenching and tempering—conferred upon metal components the necessary qualities of strength, toughness and hardness. Finally components of the exact size and shape, to the limits of accuracy laid down by the specifications, were made, chiefly by turning, boring, milling and grinding. As each component was completed, it was examined by one or more gauges to ensure that its dimensions were those specified.

When a gun had been completed to the satisfaction of its makers it was sent on to the Inspection Department for final checking, followed by proofing[2] or firing tests. If it passed these successfully it was taken down and carefully examined, visually and by means of gauges, to make sure that it had stood up to the tests. Finally the gun was reassembled ready for issue to one of the armed services.

The factory at Maribyrnong, designed for the manufacture of guns up to a calibre of 4 inches, was housed in five workshops and included a large 1,500-ton forging press. By the time the tools, jigs and gauges for the 18-pounder had been made and the extensive experimental work needed to establish the manufacture of some of the more difficult major components of the gun had been completed, the shadows of the coming world-wide depression began to fall over Australia. No 18-pounder guns were ever made. Instead, faced with the prospect of seeing the factory closed down, administrators were obliged to fight hard to keep together the staff, then numbering about 150, and to keep alive the knowledge and practice of the techniques already established. In place of guns the Ordnance Factory manufactured motor-car components, as has been told in Chapter 1.

As Australia began to emerge from the economic depression, the Ordnance Factory received its first order for guns from the Department of the Army. This order was for 3-inch anti-aircraft guns. Designed during the war of 1914-18, this gun had been adopted in Britain as a standard gun for defence against attack by aircraft. In the early thirties it had been modified to embody an important new principle of gun construction known as autofrettage. Before the adoption of this principle, medium-calibre guns of British origin (of which the 3-inch was one) had an inner tube upon whose exterior many layers of thin, flat (ribbon-shaped) steel wire were wound under high tension, which by setting up compressive stresses throughout the wall of the tube greatly strengthened it. An outer gun jacket was then expanded by heat and shrunk on the inner tube by

[2] A proofing trial was a functioning trial which simulated the most severe conditions likely to be met in service.

cooling, thus forming a "built-up" gun or ordnance[3] in a pre-stressed condition, the inner tube being in a state of compression and the outer jacket in tension.

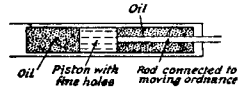
The great disadvantage of the "built-up" method of gun manufacture was that once the inner tube of the gun became worn, as was inevitable after firing many rounds, its replacement was a major operation which could only be carried out in a well-equipped factory, and which, moreover, often took several months.

During the expulsion of a shell a gun tube was subjected to a radial bore pressure of many tons per square inch and it was to enable the tube to withstand this pressure that the "built-up" method was devised. Autofrettage, or self-hooping,[4] was another way of achieving the same objective. The method was first suggested by a French artillery officer (M. Malaval) in 1907. At first little attention was paid to his suggestion until it was taken up enthusiastically during the 1920's by Major A. E. McRae at Woolwich. The autofrettage process was applied to the loose liner of a medium-calibre gun in order to induce stresses in the walls of the liner which would oppose those produced during the firing of a shell. When so treated the liner would withstand the stresses induced by firing without the need of support from other surrounding tubes or jackets as was the case with "built-up" guns.

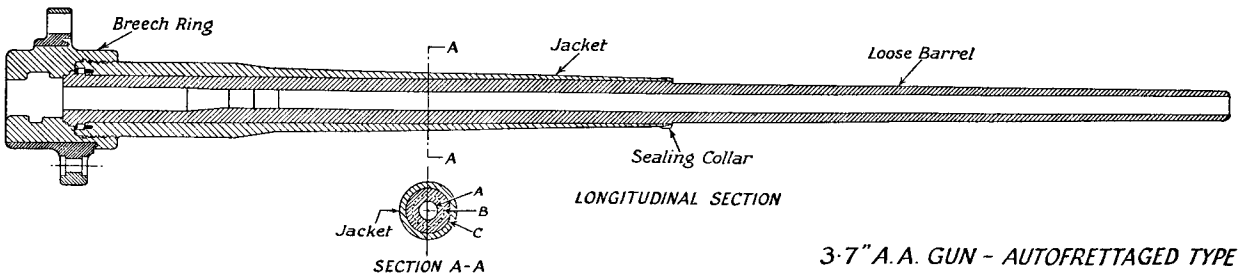
A liner to be autofrettaged was forged from nickel-chrome-molybdenum steel, heat treated to give it the required physical properties and machined to dimensions fairly close to those finally required. It was then set up in a horizontal position in a heavy fixture and a special seal was inserted in the bore at each end. Through one of these seals the liner was connected to a high-pressure hydraulic system from which glycerine was pumped into the liner at short intervals thus raising the pressure in steps of about 6 tons per square inch until the maximum or autofrettaging pressure was reached. This varied with the size of the liner and was considerably greater than the greatest pressure likely to be built up within the gun during firing. For a 3-inch gun the autofrettaging pressure was of the order of 30 tons per square inch, whereas the maximum pressure during fighting was not more than about 20 tons per square inch. After being heat treated at a low temperature the liner was again expanded in steps by forcing in glycerine as before, and the whole process was repeated. Normally this completed the autofrettaging.

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[3] That part of a gun which consisted of the outer jacket, the inner tube or tubes, the breech ring and breech mechanism was known as the ordnance. This was set up in a mounting which contained the recoil gear, fire-control, and other ancillary equipment. In a field gun the mounting, which was on wheels, was called the carriage. Recoil of the ordnance after firing was absorbed by two powerful springs whose stored energy during the return stroke was absorbed by a recuperator. This consisted of a cylinder containing oil and a piston attached by a connecting rod to the moving ordnance, which was slowed down by the passage of oil through fine holes in the piston from one side to the other within the cylinder.

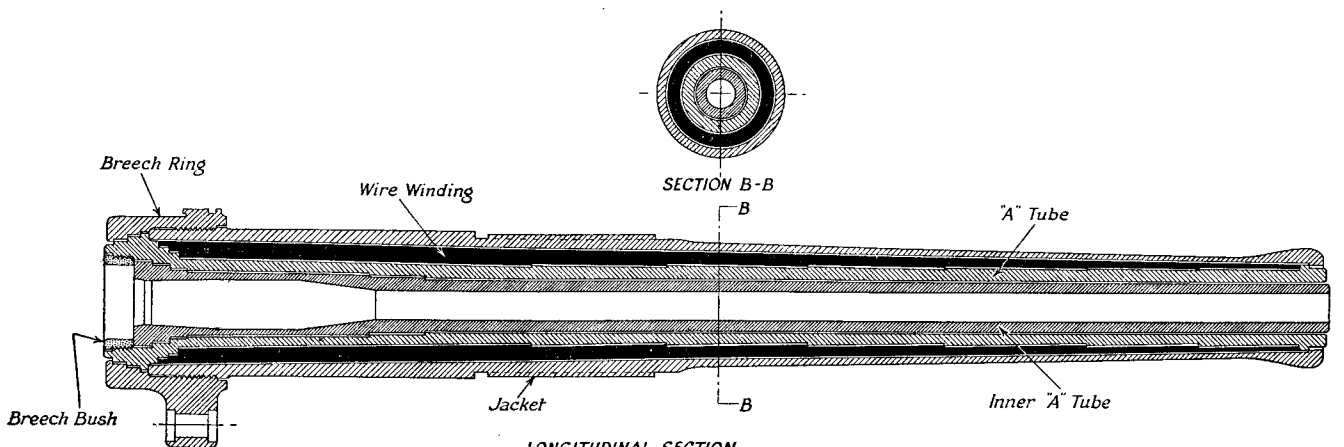


[4] This method of strengthening tubes has also been applied to equipment used in conducting large-scale chemical reactions at high pressures. There were many other highly specialised and unusual processes applied to gun making. Autofrettage has been selected, somewhat arbitrarily, to illustrate the kind of activity that was being carried out at the Ordnance Factory between the two wars.



3·7" A.A. GUN - AUTOFRETTAGED TYPE

Scale. Approx. 1/32 Full Size



6" NAVAL GUN - WIRE WOUND TYPE

Scale: Approx. 1/40 Full Size

Dept. of Defence Production

The effect of the application of the autofrettage pressure to the bore was to stress beyond its elastic limit the steel near the innermost surface. In a region about half way between the bore and the outer surface of the liner ("B") the steel was stressed just up to its elastic limit. Beyond this intermediate region all steel to the outer surface was stressed within the elastic limit. When the pressure was slowly released, steel beyond "B" endeavoured to return to its original dimensions, while that near the bore, having taken a permanent set, was unable to do so. The net effect was that the outer region was in a state of residual tension and the inner region was in a state of residual compression. The purpose of the low-temperature heat-treatment was to restore the innermost layers to their original compressive elastic limits, thus bringing the liner as a whole into a condition of stability. Under the repeated applications during firing of an explosive pressure not exceeding the autofrettage pressure, the steel of the liner remained within the elastic range and after expansion would return to its original shape.

This method of construction, which enabled the inner tube of a 3-inch gun to be replaced within half an hour and near the field of battle, represented an important advance in gun design. Its value was quickly recognised in Australia, and O'Loughlin, then Works Manager of the Ordnance Factory, was sent to Woolwich in 1934 to study and report on it.

By the end of 1936 the autofrettage process had been well established at Maribyrnong and the first 3-inch gun, consisting of ordnance, mounting and four-wheel travelling platform, was completed. Before it could be accepted for service it had to undergo extensive proofing tests. Since it was necessary to observe the fall of shells and to recover them, the proofing range had to fulfil a number of stringent conditions. It had to be in a reasonably accessible but uninhabited area on the edge of tidal water where the rise and fall of this tide was such that shells could be fired into the water where their fall could be easily observed and then recovered at low tide. In this way shells could be inspected for the effect of the actual firing, since by falling into water they would suffer no damage by impact. There are few stretches of the Australian coastline which satisfy all these conditions. One such stretch is at Port Wakefield, South Australia. Here early in 1937 the first 3-inch gun successfully passed all its tests and was accepted by the army.

This was an event of considerable historic importance in the field of munitions manufacture, since it marked the successful establishment in Australia of the technique of making guns. Those who pioneered this effort were the production engineers, shop foremen and skilled tradesmen at the Maribyrnong Ordnance Factory; the Army Inspection staff who were responsible for the issue of all drawings and specifications for the gun, and also for the examination and acceptance of the gun and its components; the staff of the Central Drawing Office who prepared drawings of the tools, jigs and gauges required in manufacturing operations; and finally the staff of the Munitions Supply Laboratories who gave invaluable assistance especially in connection with metallurgical and measuring prob-

lems. This team, which later included the Navy Department Inspection Branch, was to be of the greatest value to the defence of the country when on the outbreak of war about two years later the help of commercial industry was enlisted in the manufacture of guns.

Up to this time, when beginning the manufacture of a new munition in Australia, it was customary to import the first lot of materials from Britain and then, with the practical knowledge gained in their manipulation, to investigate their local production. Gun steel was imported only for the first batch of 3-inch guns. Not long afterwards the Commonwealth Steel Company succeeded in making the steel from which all later batches were made. In supplying gun steel and uniformly high-standard castings (both ferrous and non-ferrous) for the 3-inch gun, commercial industry gained experience in classes of work it had not previously undertaken.[5]

The 3.7-inch Anti-Aircraft Gun. That the 3-inch gun was more or less obsolete by the time it was first made in Australia was not so serious as it might seem at first sight. By making this gun the Ordnance Factory had gained experience that, in 1939, enabled it to turn with some confidence to the manufacture of the 3.7-inch anti-aircraft gun, which had come into production in Great Britain two years earlier. The Assistant Manager of the factory, Mr Parker,[6] was sent to England to study the manufacturing processes at first hand. Manufacture of the 3.7-inch gun and mounting presented the usual technical difficulties associated with larger guns. Nevertheless, ten months after receiving the drawings the Ordnance Factory turned out the first gun, in May 1940. This was the beginning of the Ordnance Factory's large-scale contribution to the stock of weapons used in the war of 1939-45.

The 3.7-inch gun differed from its predecessor in that it was operated in conjunction with a predictor, a complicated mechanism—essentially a calculating machine—designed to direct the fire of a gun on to a moving target. The muzzle velocity of a 3.7-inch anti-aircraft gun was approximately 2,000 feet per second and thus a shell issuing from it would require about 14 seconds to reach an altitude of 10,000 feet. An aircraft flying at 300 miles per hour would during that time travel a distance of 6,160 feet, or more than a mile. A gun was therefore aimed at a point ahead of the position of the aircraft at the instant of firing, such that the time required by the shell to reach this point, called the "future position", was the same as that taken by the plane to travel from its "present position" to the same point. When the relevant data such as speed, altitude, distance and direction of plane were fed into the predictor it calculated quantities which would permit the gun to be accurately aimed.

Manufacture of the predictor offered considerable difficulty and the first 3.7-inch guns from Maribyrnong were fitted with imported instruments.

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[5] Cockatoo Docks Engineering Co Pty Ltd supplied manganese bronze castings for gun cradles; so also did W. O. & B. Adams (Melbourne).

[6] V. C. Parker. Assistant Manager, Ordnance Factory, Maribyrnong, 1938-40; Manager, Ordnance Factory, Bendigo 1940-46, Maribyrnong 1946-50. Of Melbourne; b. Dapto, NSW, 28 Aug 1900.

A predictor consisted of complicated gear trains made up of spur, bevel and differential gears arranged to give mechanisms and mechanical motions representing mathematical equations, and obviously called for high-grade instrument engineering. Ford,[7] an engineer from Maribyrnong, had studied predictor manufacture at Vickers Ltd in England. On his return to Australia he succeeded, with the help of two British foremen, in establishing this phase of precision-instrument engineering. With the exception of alternating control units known as magslips (supplied by Standard Telephones and Cables Pty Ltd, Sydney), 15-way twin sockets (from Stokes and Co, Melbourne) and clockwork components (from England), the predictor was entirely the work of the Ordnance Factory. Within about eighteen months it was in production and was completed in time to equip, for example, guns fired against the Japanese during their attacks on Darwin early in 1942.

As there had been some opposition in Britain to Australia's being given the opportunity of manufacturing the predictor—it was considered beyond the capacity of her industry—there was justifiable elation when at the trials at Werribee the first shot took the tail off the sock trailing from the aircraft. Maximum output of predictors was at the rate of three a month and the total number made was fifty-two. Although each predictor normally served four guns, this number was far from sufficient for all the 3.7-inch anti-aircraft guns made in Australia. Towards the end of the war an automatic fuse-setter and loader, which enabled the gun to be fired at intervals of 2½ seconds, was added. The automatic loader, like the predictor, was an intricate mechanism involving a good deal of electrical work.

Throughout the war improvements were continually made in the machining operations on the 3.7-inch, and other, guns. Special attention was given to extending the use of tungsten carbide for high-speed cutting. Honing of the barrels was greatly speeded up and improved in quality by means of a new type of machine imported from the United States. A new type of tool for rifling the bore of the gun, known as a circular broaching tool, had been developed at the United States Government Arsenal at Watervliet in 1941, and the authorities there generously gave drawings of the tool to Australia in the same year. Instead of making rifling grooves two at a time, as was done by the older method, the circular broaching tool formed them all simultaneously by removing shavings of steel two thousandths of an inch thick from the grooves at each pass through the bore. Removal of such thin, continuous layers of steel was testimony to the high quality of the gun steel. Some idea of the extent of the improvement on existing rifling tools may be gained from the fact that the new broaching tool reduced the time taken to rifle a 3.7-inch barrel from twelve hours to four and a half.

Production of the 3.7-inch gun in Australia soon after its adoption by the United Kingdom was evidence of the close liaison between the two countries. Advance drawings and specifications had in fact been sent

[7] P. G. Ford. Draughtsman Ordnance Factory, Maribyrnong, to 1939, Engineer-in-charge Prediction Section from Jan 1941. Of Melbourne; b. Lithgow, NSW, 9 Jan 1914.

to Australia some time before the gun was issued to the British Services, and Australia was thus kept abreast of modern technical developments. The first 3.7-inch gun was completed early in 1940, and in August of that year four were shipped to Darwin. Others were sent to the United Kingdom and set up in Hyde Park, London, where to the great satisfaction of Australian munitions authorities they played their part in defending the city against the great air raids of the latter part of 1940. Others again were sent to Singapore, only to be captured later by the Japanese.

The 25-pounder gun-howitzer. Until after the outbreak of the war of 1939-45 the majority of field weapons in the British Army were 3.3-inch 18-pounder guns or 4.5-inch howitzers, both survivors from the war of 1914-18. Each type had its special role: the gun, firing a projectile with a high velocity and flat trajectory, could be accurately aimed at a target with a minimum of elevation; the howitzer, firing a projectile with much lower velocity and range, could be directed at such a high elevation that the projectile would fall almost vertically on its target.

The 25-pounder, adopted by the British Army just before the second world war, was designed to perform the functions of both gun and howitzer, duality of function being achieved by modifying the explosive charges used to fire the projectile. Four types of charge gave a wide variation in range and muzzle velocity, as can be seen from the accompanying table.

Charge	Muzzle velocity ft/sec.	Max. range yds.
I	650	3,900
II	975	7,800
III	1,450	11,800
Super	1,700	13,400

Ability to fire projectiles with high muzzle velocities made the 25-pounder a useful anti-tank gun, while its wide range of depression and elevation (— 5 degrees to + 40 degrees) made it most effective in mountainous terrain. In fact the 25-pounder proved to be one of the most successful field guns of its time.

The suggestion that the 25-pounder should be manufactured here was made by Colonel Sturdee[8] of Army Headquarters as early as 1938. His proposal was supported enthusiastically by Mr Jensen, then Controller of Munitions Supply. However, it takes more than the satisfactory solution of design and production problems, and the request for a weapon, to bring it into being. Proposals that the Government should manufacture the 25-pounder were at first opposed by the Chairman of the Treasury Finance Committee, Sir Walter Massy-Greene.[9] The delay that occurred in begin-

[8] Lt-Gen Sir Vernon Sturdee, KBE, CB, DSO. (1st AIF: CRE 5 Aust Div 1917-18; GSO 2 GHQ BEF France 1918.) GOC Eastern Comd 1939-40; CGS 1940-42, 1946-50; i/c, Mil Mission, Washington, 1942-44; GOC First Army 1944-45. Regular soldier; of Melbourne; b. Frankston, Vic, 16 Apr 1890.

[9] Hon Sir Walter Massy-Greene, KCMG. MHR 1910-23; Senator 1923-38; Min for Trade and Customs 1919-21, Defence and Health 1921-23; Asst Treasurer 1932-33. Company Director; of Sydney; b. Wimbledon, Eng, 6 Nov 1874. Died 16 Nov 1952.

ning the manufacture of a weapon of such critical importance to the defence of the country was, in the opinion of those responsible for the production of munitions, a serious one, but one for which neither the Munitions organisation nor the army was to blame.

On 18th January 1940 the War Cabinet approved the construction of a new gun factory estimated to cost £300,000. Within about six months the factory was completed, but manufacture of the 25-pounder could not begin because drawings of the gun had not arrived. The field artillery of the Australian Army was at this time limited to 18-pounders, mostly of the 1914-18 vintage. During the great reorganisation of munitions manufacture in June 1940, the Chief of the General Staff, General Sir Brudenell White, is reported to have told the Prime Minister: "If the enemy landed they (the 18-pounders) would not last us over a month's fighting. There is no use blinking at that." While this was undoubtedly an exaggeration it indicated the strength of the army's views on the need for a large number of more modern guns.

On learning that the 25-pounder was about to go into production in Canada, Mr Essington Lewis, greatly perturbed at the long delay over the gun, sent a cable to Sir William Glasgow, Australian High Commissioner in Canada, asking for assistance in procuring drawings and specifications. Within a few days Glasgow replied that some drawings had been despatched from San Francisco on 24th July. By the end of August nearly all the important drawings had arrived.[1]

Orders for 25-pounders and other guns placed during and soon after June 1940 so far exceeded the capacity of the government factory in spite of the recent extensions to it that the only hope of meeting them was to call in the help of commercial industry. The factory had worked out the preliminaries for the line flow production of several types of gun and was ready with a complete scheme for handing over a large share of production to commercial industry. The automotive industry, by reason of its long and extensive experience of production engineering, figured largely in the new plans and it was no accident that Mr Hartnett, the Managing Director of General Motors-Holden's, was appointed head of the newly-formed Directorate of Ordnance Production. For Hartnett, who had begun his wide-ranging engineering career during the 1914-18 war at the armament firm of Vickers Ltd in England where he served his apprenticeship, the wheel had come full circle. In conformity with the general policy of having an administrator with experience of the government munitions organisation to assist the director, Mr Daley, who some years before the war had been an assistant manager in the Ordnance Factory, was appointed Controller.

The directorate's responsibility was at first limited to developing within commercial industry the production of guns and their ancillary equipment,

[1] The following are a few particulars of the ordnance:
Weight: 1 ton 15 cwt 1 qr 20 lb (inc breech mechanism).
Bore: Calibre 3.45 in, length 92.375 in.
Rifling: polygroove—length 74.235 in; uniform 1 turn in 20 calibres.
Grooves 26—depth 0.04 in, width 0.2777 in.

such as optical and electrical instruments for fire control. The general plan was that the government factories would make the larger and more complex guns: 3.7-inch and 25-pounder ordnance at Maribyrnong and the 4-inch naval guns and carriages at Bendigo. Commercial industry, organised by the Ordnance Production Directorate, would produce trailers and carriages for the 3.7-inch, the 25-pounder and the smaller guns. The original plan was not followed exactly. Commercial industry did make ordnance pieces for the 25-pounder. In a short time the Ordnance Production Directorate's activities were enlarged so that it handled a far wider variety of war material than any other directorate. Its interests ranged from mobile laundries and cookers to torpedoes, telephone cable, electric generating sets, optical instruments and "tropic proofing". After 1943 it did a great deal to assist the production of agricultural machinery, but when first formed in 1940 its main concern was with guns—in particular the 2-pounder anti-tank gun and the 25-pounder gun-howitzer.

The sequence of the directorate's operations was roughly as follows: as soon as an order (in this instance for trailers and carriages of the 25-pounder) had been received, the relevant drawings and specifications were examined with a view to deciding the Australian equivalents of the materials (principally steels and other alloys) called for and also to calculating the quantities that would be required. These questions were discussed with the Director of Materials Supply (Sir Colin Fraser) who was able to state whether the materials were available or not. Where shortages were evident, alternative materials were sometimes sought. A good example of this was the Australian bullet-proof steel, which avoided the use of nickel, then extremely scarce. To deal with other shortages, for example gun steel, new centres of production were set up. An electric furnace and auxiliary equipment for making gun steel were installed at the Brooklyn works of the Melbourne Iron and Steel Company.

The nature and extent of the tooling and gauging necessary to meet the rate of production agreed upon was then discussed with the Director of Machine Tools and Gauges (Colonel Thorpe). Owing to the general shortage of machine tools a good deal of improvisation was often necessary.

In the meantime the directorate's production engineers, in cooperation with the Boards of Area Management in each State, sought out suitable firms to undertake the manufacture of components. A salient feature in the plan of production was the appointment of a major coordinating contractor, whose special responsibility was to coordinate the work of the many sub-contractors. For the manufacture of the 25-pounder two large engineering firms were chosen: Charles Ruwolt Pty Ltd (associated with Thompson's Engineering and Pipe Co Ltd of Castlemaine) for Victoria, and General Motors-Holden's for New South Wales. Each firm cooperated with the directorate, in planning production, organising sub-contractors, defining the requirements of gauges, cutting tools, jigs and fixtures, ordering materials and the final assembly of the finished gun.

Before manufacturing began production engineers of the directorate often made requests to the Army Inspection Branch for permission to

modify specifications to meet Australian technical practice or to allow for the use of Australian materials that differed slightly from corresponding British materials. The system for requesting these changes was so simple and flexible, and so wholeheartedly supported by Colonel Gipps, that no small part of the efficiency of the directorate's activities must be attributed to this form of cooperation with the Inspection Branch.

With the single exception of ball bearings all the 5,000 components of the 25-pounder were made in Australia. Some of the larger and more difficult components were made by the major coordinating contractors; this often involved them in designing and building special-purpose machine tools for the work. The two major firms were obliged to call in the assistance of nearly 200 sub-contractors, who were as strange to the work of making guns as they themselves were. That the whole project was completed with so few hitches and in such a short time was testimony to the industrial adaptability and ingenuity of all the firms concerned.

Australian Iron and Steel forged barrels, the Colonial Sugar Refining Co machined them, Australian General Electric made trails, Melbourne Tramway Workshops the platforms, Chubb's Australian Co Ltd, recuperators, Automatic Totalisators Ltd dial sights, and Claude Neon Ltd (Victoria) spirit levels. This very incomplete list is quoted in order to emphasise once more that the manufacture of the 25-pounder gun, like most other munitions made by commercial industry, was very much a team effort. It would be wrong to imply that there were no failures and hold-ups. The recuperator, a vital part of the carriage of the gun, was for some time a source of considerable anxiety to the major contractors in New South Wales. The firm to whom its manufacture was first entrusted—one of the most highly regarded engineering firms in the country—failed. It was then turned over to Chubb's Australian Co Ltd, makers of office safes, who made a success of it. The Victorian major coordinating contractor (Ruwolts) early recognised that the recuperator was a difficult piece of engineering and did not sub-contract it.

Forging and heat-treating the chrome-molybdenum steel for the recuperator (both carried out by the Thompson Engineering and Pipe Co Ltd) were by no means simple operations, but the real problem was the machining of the block: three holes, each of a small but accurately known diameter, had to be bored through the full length of 65 inches in such a way that they were parallel to within an axial limit of a few thousandths of an inch. The firm's technical staff designed and built a machine tool which enabled the three holes to be bored simultaneously. Of this difficult component Ruwolts made no less than 1,024, some of which were supplied to General Motors-Holden's.

The first 25-pounder carriage and ordnance to be made wholly in Australia was completed in May 1941 in the works of Charles Ruwolt. Government and commercial engineering works both contributed parts to this first gun. By 31st October 1941, nine months after the receipt of the drawings, the first complete gun to be made entirely by commercial industry came off the assembly line of General Motors-Holden's and was

successfully proofed on 26th November. This particular gun was fitted with a recuperator made in Victoria.

The output of 25-pounders to the end of 1943, when it ceased, was: 1,173 ordnance and 230 spare barrels made by the government factory, and 354 ordnance and 445 spare barrels made by industry. The carriages and trailers for use with these were made entirely by commercial industry —principally by Charles Ruwolt Pty Ltd, General Motors-Holden's and Ruskin Pty Ltd of Victoria.

The 25-pounder short (Aust) quick-firing gun-howitzer. Despite its adaptability as a howitzer, the 25-pounder was not suited to remote jungle or mountainous terrain because of the difficulty of transporting it. For use in these circumstances it was considered desirable to redesign the gun so that it could be broken down into comparatively light units—light enough to be dropped by parachute or to be packed into a jeep—which could be quickly reassembled. To meet these special requirements Brigadier O'Brien[2] (Director of Artillery) suggested to the M.G.R.A. in September 1942 that the 25-pounder should be redesigned by shortening the barrel and the recuperator and by making the trail lighter. Advantage was taken of the fact that Ruwolts had just redesigned the recoil system of the 25-pounder to enable the standard gun to be mounted in the Australian cruiser tank, an adaptation which proved equally suitable for a short 25-pounder.

Redesign of the gun to meet the new requirements without adversely affecting its valuable ballistic characteristics was carried through by the staff of the M.G.O. Design Division under Major Emery,[3] in collaboration with the Ordnance Production Directorate and Charles Ruwolt Pty Ltd. The gun was made so that it could be broken down into ten pieces, all of which could be dropped by parachute. Assembled, it could easily be towed by a jeep, and this was an advantage as the jeep could be carried in an aircraft. The maximum range of the modified (short) gun was approximately 87 per cent of that obtainable with the standard gun.

The muzzle velocity and maximum ranges expected for the short gun were as shown in the accompanying table.

Charge	Muzzle Velocity in feet per sec.	Maximum Range in yards
1	565	3,100
2	837	5,700
3	1,248	10,400
Super	1,464	11,500

Instructions issued by the Master-General of the Ordnance warned artillery officers not to use the super charge, except in conditions of extreme urgency, on account of the severe strain likely to be imposed on the light carriage.

[2] Maj-Gen J. W. A. O'Brien, DSO, ED. CO 2/5 Fd Regt 1941-42; Dir of Arty LHQ 1942-43; DMGO (Army Eqpt) LHQ 1943-44. Consulting engineer; of Glen Iris, Vic; b. Melbourne, 13 Jun 1908.

[3] Maj H. W. Emery. Asst Superintendent of Design LHQ 1943-45. Electrical engineer; of Camberwell, Vic; b. South Melbourne, 26 Sep 1899.

The prototype was proved early in December 1942 and after several minor modifications had been introduced as a result of the proving, large-scale production was begun early in 1943. Altogether 213 short guns were manufactured. Artillery officers were unanimous that Australian industry had done a remarkably good job on the standard gun (25-pounder Aust Mk II); their opinion of its performance in the field seems to have been uniformly high. On the qualities of the short gun there were extremely divergent views. There is reason to believe that much of the criticism of the short gun arose from the fact that more was expected of it than its designers intended. Critics lost sight of the fact that the "short" was a special-purpose weapon, and that some sacrifices of performance of the standard weapon had to be accepted in order that it might fulfil its special roles. Because of its light weight it tended to be "lively" when fired. The need to save weight made the gun less suitable for sustained heavy firing. The short barrel caused a heavy blast effect on the crews, who, in consequence, sometimes suffered from severe earache and temporary deafness, as well as occasional nose-bleeding. Whatever the gun's shortcomings may have been they appear to have been outweighed by its good points.

The short 25-pounder was dropped by parachute on Wednesday 8th September 1943 with a troop of the 2/4th Field Regiment landing behind Lae—probably the first time such a heavy gun had been dropped in action anywhere—and was used to good effect in some later operations in New Guinea.

Anti-tank Guns. Anti-tank guns occupied a high position on the 1940 lists of the Australian Army's requirements. The main British weapon then in use against tanks was the 2-pounder, a rapid-firing high-velocity gun which had gone into production in Britain just before the war.

The decision to make the 2-pounder anti-tank gun in Australia was taken early in 1940, and the Ordnance Factory immediately began to make preliminary plans and to obtain manufacturing information, all of which it handed over to the Ordnance Production Directorate. Within a short time the directorate placed an order for 1,000 guns with General Motors-Holden's, Woodville, South Australia, which was appointed major coordinating contractor. Having taken a specimen British gun to pieces General Motors-Holden's, in conjunction with the Ordnance Production Directorate and the South Australian Board of Area Management, called in potential sub-contractors to view the various components and select those they thought they could make. General Motors then assumed responsibility for making the parts no other firm would undertake. Few firms were so experienced as General Motors-Holden's in the layout of factory processes, the manufacture of tools and gauges, the marshalling of raw materials (some 90 different kinds were required to make the 4,000 parts of a 2-pounder anti-tank gun) and in the coordination of sub-contractors so that components would arrive at the assembly line on the appointed time. The Ordnance Factory at Maribyrnong instructed engineers from

General Motors in some of the techniques of making guns, and provided opportunities for them to study production methods peculiar to such work.

The Ordnance Production Directorate did not rely on the government factories and laboratories alone for its technical information. By sending its engineers abroad it arranged for a constant flow of up-to-the-minute information on the latest developments. Occasionally there was too much zeal in this direction, as for instance when the directorate introduced Magnaflux equipment for the detection of cracks and flaws in metals. In this method a liquid consisting of fine iron particles dispersed in kerosene was poured over a steel component resting in a magnetic field. Cracks or flaws invisible to the naked eye were quickly revealed by the disposition of the iron particles. The method was tried out on the forged breech-blocks of the 2-pounder after they had been machined. To the astonishment of many engineers, including those of Army Inspection, nearly every breech-block so tested revealed numerous fine flaws and irregularities. This brought production almost to a standstill until it was discovered that the breech-block from a sample gun sent out from the United Kingdom showed just as many flaws. When the question was taken up with Woolwich Arsenal, the authorities there explained that although Magnaflux equipment had not been in use when the 2-pounder gun was being designed, the designers had been aware that forgings of the kind used for the breech-block carried many fine flaws and folds, and they had therefore provided extra thickness of metal to give sufficient strength and to allow for possible weaknesses arising from such flaws.

There were many problems to be solved in fabricating gun steel; new practices in drop forging and machining had to be adopted. The barrel of the 2-pounder was the "monobloc" type and did not require to be autofrettaged. The main challenge to engineers in manufacturing the gun was to meet the exacting specifications for the heat treatment of the steels and to attain the necessary high degree of precision in the bore, rifling and traverse and laying mechanism. The company itself thought the gun was no easy job: ". . . the first of the weapons we produced was one of the most difficult placed in quantity production and this has been generally agreed to by those in other countries where this weapon has been manufactured." In spite of difficulties the gun was produced with remarkable speed: the sample gun from Britain was examined by General Motors-Holden's in Adelaide in June 1940; the first gun passed proofing tests in April 1941.

When plans were made to manufacture guns in Australia they were drawn up on the assumption that all the optical equipment needed for fire-control could be imported from the United Kingdom. This assumption proved wrong, and for a time the first 100 Australian-made 2-pounder guns were without sighting telescopes. The story of how this deficiency was remedied involves such a long digression that it is postponed until the next chapter.

No sooner had the 2-pounder guns begun to come off the assembly line than operations in the Libyan Desert showed that the gun was unable to

penetrate the armour of German heavy tanks; steps were already being taken in Britain to meet such a challenge. The first answer was the 6-pounder, or 57-millimetre gun. Designs were sent to Australia. General Motors-Holden's, beginning manufacture in July 1941, did not lag far behind Britain: the first Australian 6-pounder was delivered in July 1942. Although this gun was a great improvement on the 2-pounder, it could do little more than dent the armour of the heaviest tanks then in use.

A second attempt to overtake the lag in offensive weapons brought to the fore a very much heavier gun—the 17-pounder. Manufacture of this gun, the latest British development in the unending contest between weapons of offence and defence, was authorised by the Australian War Cabinet on 28th August 1942. Australia was, in fact, the only country other than the United Kingdom to manufacture the 17-pounder.[4]

Designed in 1941, the 17-pounder anti-tank gun incorporated all the best features of earlier guns. One aim of its designers was to secure a high muzzle velocity with a correspondingly flat trajectory. Charles Ruwolt Pty Ltd, by reason of the experience gained in the manufacture of the 25-pounder gun, was chosen as the major coordinating contractor for the carriage of the 17-pounder. The Maribyrnong Ordnance Factory made the ordnance. The final operations in the South-West Pacific Area made so few demands for a powerful anti-tank gun that only a small number of 17-pounders were made. Figures for the output of anti-tank guns were:—

2-pounder . .	892
6-pounder . .	900
17-pounder . .	128

The Bofors quick-firing anti-aircraft gun. A basic weapon of the war and the standard light, rapid-firing, anti-aircraft gun was the 40-millimetre Bofors.

When the first order for these guns was received from the army, in January 1941, the Ordnance Factory set aside a section of the machine shop for their manufacture; as only 43 guns were asked for and the job was a complex one, it was decided not to sub-contract any of the work. In October 1941, a few weeks before the first gun was passed to the Inspection Branch, a second order came from the army, this time for 500 guns. Since it was clear that the tooling designed for the manufacture of 43 guns at a slow rate would be quite inadequate for the manufacture of a large quantity at an accelerated rate, it was decided, first, that the Ordnance Production Directorate should arrange for some of the components to be made by commercial industry, and second that considerable modification and redesign of tooling were necessary within the Ordnance Factory. To conserve floor space and speed up production a number of special machine tools were designed and built at Maribyrnong. For instance, the operation of machining guides in the breech casing took eight hours in a large shaper; by designing and making a special milling machine

[4] Duncan Hall and Wrigley, p. 416.

the factory reduced this time to two hours and left the shaper free for other work.

Under the direction of the Ordnance Production Directorate commercial industry made such important components as the buffer, firing gear, hand elevating gear, firing platform, lifting jacks, and brakes. The main sub-contractors were the Ford Motor Company, Messrs H. V. McKay-Massey Harris, and the Paton Brake Company.

From one gun a month in July 1942, production rate rose to 25 a month by August 1943. In October of that year the orders, which then totalled 1,200, were greatly reduced and production was tapered off to 10 a month. In all, 290 complete guns were made and 700 spare barrels. While a good job was done in making most of the parts for the 290 guns, it must be mentioned that two very important components—the oil units which actuated the mechanical movements of the gun, and the automatic loader—had to be imported. Orders ceased just as arrangements had been completed for Australian Glass Manufacturers Pty Ltd of Sydney to begin production of the automatic loader.

The 4-inch Naval Gun. The heaviest gun made in Australia during the war was the 4-inch Mark XVI naval gun, of which two types were made: the standard gun used on naval ships, and also a much lighter gun with a hand-operated light mounting designed chiefly for use on merchant ships for protection against submarines.

The standard naval gun was used on two types of mounting: the single mounting which carried a single ordnance, and a twin mounting which carried two 4-inch ordnance (a right-hand and a left-hand). The ordnance factory at Maribyrnong supplied the ordnance for both mountings. Only the single mounting was made in Australia during the war, chiefly by the Naval Establishment at Garden Island. The establishment acted as major coordinating contractor for this difficult project, which was placed under the supervision of Engineer Commander Urquhart.[5]

Except for the fire-control equipment, the light gun was made entirely at the Bendigo Ordnance Factory. The total number made was 230.

Relining large naval guns. One of the most unusual and technically difficult jobs undertaken in the field of ordnance production during the war was the relining of 8-inch naval guns, the largest guns of the Australian Navy. No advantage could be gained by applying the method of autofrettage to the manufacture of guns of large calibre, since with so heavy a barrel it was impracticable to reline them on the spot. Guns of large calibre were manufactured by the "built-up" process described earlier, and their relining could only be done in properly equipped workshops. By the middle of 1941 the menace of German submarines had reached such proportions that it was feared that if 8-inch guns from Aus-

[5] Eng Capt K. McK. Urquhart, RAN. I/c Gunmounting Depot and Torpedo Depot RAN 1939-44; HMAS's *Arunta* and *Warramunga* 1944; *Napier* 1944-45. Gen Manager, Garden Island Dockyard, since 1954. B. Launceston, Tas, 28 Feb 1905.

tralian cruisers had to be sent to Britain to be relined when their inner tubes had become worn out, there would be considerable risk of their being lost through enemy action.

The difficulty of the job lay mainly in the size of the ordnance, which was 35 feet long and weighed 17 tons, whereas the largest gun previously handled by the Government Ordnance Factory was the 4-inch Mark XVI Naval Ordnance which was 16 feet long and weighed only 2 tons.

Outside Britain there were, in 1941, no facilities anywhere in the British Commonwealth for carrying out work of this kind. When the question of relining naval guns first came up for consideration, a new government factory intended for the production of heavier types of ordnance was in the course of construction at Bendigo, Victoria, and it was decided to equip a section of it for building and relining large guns. With this in view O'Loughlin visited the United States to study methods of building heavy guns and to purchase essential machinery then unprocurable in Australia.

The United States authorities gave him access to two of their most important establishments, the Washington Naval Yard and Watervliet Arsenal, at which medium and heavy guns were made. All the information sought was readily supplied—even to a set of drawings of a newly developed type of circular rifling cutter which, when adopted soon afterwards in Australia, brought about a great saving in costs and man-hours in gun manufacture.

Canada was equally cooperative. Government authorities there, realising the significance of the relining project to the defence of Australia, went out of their way to help by making available, at the expense of their own requirements, heavy-gun boring and engine lathes which could not, at that time, be purchased anywhere else.

In its original form, that is, before relining, the body of the 8-inch naval gun consisted of three separate pieces: the "A" tube, which contained the rifled bore through which the shell passed; a "B" tube which was shrunk on to the "A" tube to give it support; and an outer jacket which was shrunk on the "B" tube. Together the three pieces formed what was known as a "built-up" gun. Shrinking on was achieved by slipping the outer tube "B" on to "A" while the former was in a hot expanded condition, and then cooling it with water.

The operation of relining involved building a new "A" tube into the gun. In the forged condition and before being machined and bored, the new lining material consisted of a solid, tapering, cylindrical forging of nickel-chrome-molybdenum steel about 37 feet long and more than 8 tons in weight, which had been roughly forged into this shape from an ingot of steel by the Commonwealth Steel Company at Newcastle. Forging was completed at the Ordnance Factory at Maribyrnong, and the solid cylinder was then transferred to the Bendigo factory where it was "rough" machined, heat treated and finally finish machined ready for insertion in the gun. At this stage the cylinder was 33 feet 7 inches long, with an outside diameter of 14.3 inches at the breech end and 9.8 inches at the

muzzle end, the rate of taper of the exterior surface being four thousandths of an inch per inch of length.

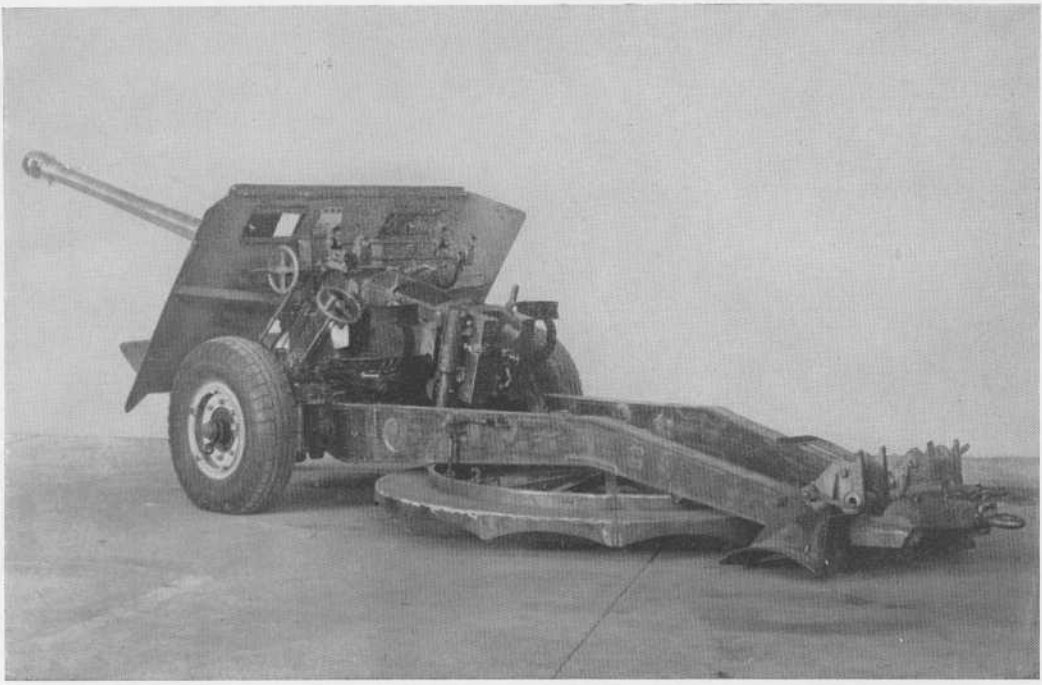
The next step was to prepare the worn gun to receive the cylinder. This was done, after some preliminary operations, by setting it up in a large gun-boring lathe more than 120 feet in length. In a series of long boring operations the existing 8-inch hole (the worn bore) was enlarged and tapered until it corresponded approximately to the external sizes of the cylindrical insert. The formation of a tapered hole 33 feet 7 inches long to a high standard of straightness, dimension and surface finish to match those of the cylinder to be inserted, was a critical operation.

Much of the success of this boring operation was due to the use of seven special reamers similar in design to those used in the heavy gun shops in the Washington Naval Yard, in the United States. They were made of flat steel cutting plates about one inch and a quarter thick, more than five feet long, and shaped to represent the taper of the hole to be bored. The cutters were attached to a steel frame backed by wood. Wood was used in order to make intimate contact with the surface of the hole during the boring operation and thus give support to the cutting tools.

When boring of the hole was completed, the gun was set up in a deep pit looking something like a small mine shaft, with the breech end uppermost and the muzzle end resting on a heavy cast iron base. The cylinder was lowered by means of a crane into the gun as far as it would go under its own weight. The cylinder having been made slightly larger than the hole into which it was to be driven, it was necessary finally to drive it home by a series of heavy blows. In the course of being driven home its exterior surface and the mating surface of the outer tube were both subjected to compressive stresses which ensured that each would sustain its share of the stresses when the gun was fired.

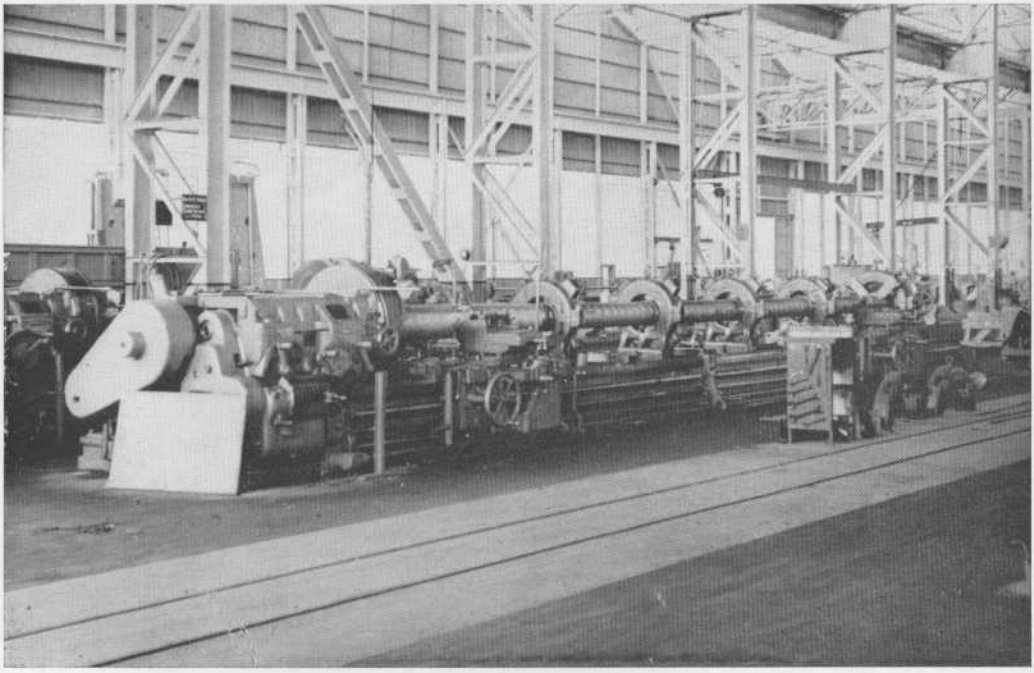
After the cylinder had been inserted, the now solid barrel was returned to the machine shop for the finishing operations, that is the boring, honing and rifling of the bore—all operations of considerable difficulty because of the size of the gun and the lack of previous experience in this work at the Bendigo Ordnance Factory. Credit for the successful relining of naval guns must go to the engineering staff of the Bendigo Ordnance Factory and to the associated Naval Inspection staff.

Measurement of the muzzle velocities of naval guns. In order to be able to fire accurately at targets out of sight whose position had been determined by means of radar, it was imperative to have accurate knowledge of the muzzle velocity of guns. For any particular gun this velocity was known at the time it left the factory or proving ground, but as the lining of its barrel became worn from repeated firing the muzzle velocity changed to a small but significant extent—enough to seriously upset the accuracy of firing. By 1942 radar-controlled, blind firing had become established as an important element of naval warfare but there was, as yet, no readily portable device available for measuring muzzle velocities of guns on ships at sea. The Navy Board posed the problem of building such a device to



(*Ruwolts*)

17-pounder gun with firing platform in towing position.



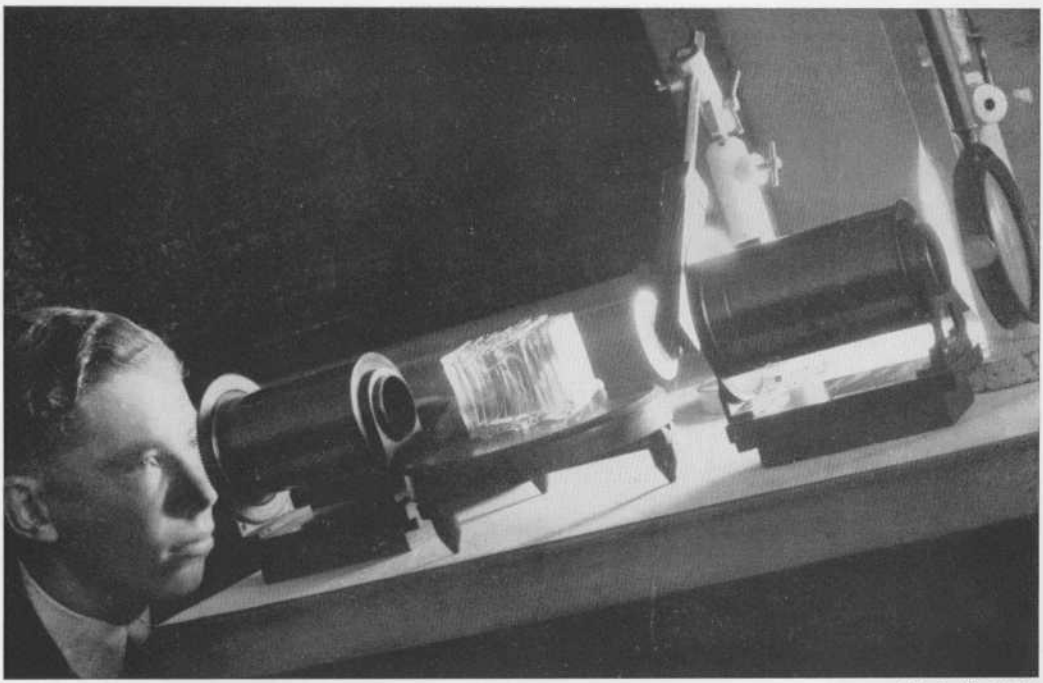
(*Bendigo Ordnance Factory*)

8-inch Gun. Turning the inner "A" tube.



(Dept of Defence Production)

A chunk of Crown optical glass.



(L. J. Hartnett)

Optical glass being tested for the absence of strain. When it has passed this rigid test it is made into lenses and prisms.

the C.S.I.R. By a fortunate coincidence Dr Bowden[6] and his colleagues in the Section of Lubricants and Bearings had, in the course of studying the transient phenomena of explosions in nitroglycerine, built an instrument known as a photo-cell chronometer which was capable of measuring extremely small intervals of time. They quickly set about adapting this to solve the navy's problem, which, put in its simplest form, was to measure the interval of time it took a shell to pass two fixed points whose distance apart was known accurately. Two light-sensitive cells (photo cells), exactly 10 feet apart, responded instantaneously to the interruption of a beam of light caused by the passage of the shell. Just as the vibrating pendulum of a clock could be used to measure time intervals in seconds, so a quartz crystal vibrating 1,000,000 times a second could be used to measure time intervals in millionths of a second. Photo-cell chronometers had of course been designed and used for this purpose in Britain, the United States and Canada. The great advantage of the instrument built by members of the Lubricants and Bearings Section in 1943 lay in the unusually small base line (10 feet) that was adopted. The advantages in portability to be obtained from such a short base were obviously great, and especially valuable where the space in front of a gun was limited, as on the deck of a ship at sea. Except for the photo cells and one other valve all the components of the C.S.I.R. instrument were locally made. All lenses and auxiliary optical equipment were designed and produced by the optical munitions annexe at the University of Tasmania. When tested at sea in September 1943 to measure the muzzle velocities of the 6-inch guns in the *Adelaide,* eminently satisfactory results were obtained. Shell velocities in the region of 3,000 feet a second could be measured with an accuracy of about 1 part in 500. The trial was notable in that it was the first occasion on which muzzle velocity measurements had been made on a ship at sea.[7]

The Admiralty showed great interest in this work. A model specially built for it was tested on the guns of H.M.S. *King George V.* Several models were also made for the army.

[6] F. P. Bowden, FRS, DSc, PhD. Director of Studies, Gonville and Caius College, Cambridge, 1935; Head of Tribophysics Lab CSIR 1939-45; Reader in Physical Chemistry, Univ of Cambridge, since 1946. B. Hobart, 2 May 1903.

[7] "Federal Government Impetus to Industrial Development", *Radio and Electrical Retailer,* Vol. 23 (1945), p. 50.

CHAPTER 12

OPTICAL MUNITIONS

ALTHOUGH radar made it possible to detect distant objects through darkness and fog, optical instruments were still essential for seeking out and accurately locating the enemy at closer ranges, as well as for directing the aiming of shells, torpedoes, bombs and rockets. The fortunes of battle could be influenced by the quality of the optical instruments used for fire control. It is the opinion of one writer that the loss of so many British ships in the Battle of Jutland could, in some degree, be attributed to the high quality of the fire-control and range-finding equipment of the German Navy at that time.[1]

Increasing dependence on optical instruments of all kinds had gone hand in hand with the growing complexity and efficiency of weapons of war and, in 1939-45, had reached such a pitch that actions were often fought at distances where combatants were no longer visible to one another. As recently as the American Civil War, the range of guns was so limited that the only targets that could be attacked effectively were those that could be seen with the unaided eyes of men near the guns. In the interval between the American Civil War and the first world war the range and accuracy of guns had been increased to the extent that it became possible to attack even relatively small targets at ranges of up to 30 miles or more. During the war of 1939-45 most of the really effective artillery fire on land was directed by gunnery officers who, usually with the aid of binoculars, could see the target and speak by telephone to the guns miles away. These ranges demanded optical instruments of the highest quality, chief among which were the dial sight director and range-finder. The advent of the submarine, tank and aeroplane called for other instruments, such as the periscope, camera, stereoscope and bombsight.

Manufacture of optical instruments was restricted to highly industrialised countries.[2] At the end of the nineteenth century Germany held a dominant position in the optical field because her industry was not only centralised and well organised, but was powerfully supported by the state. British optical industry, on the other hand, with many fine achievements to its credit, was not so well organised and did not receive state aid until much later in the day. Not until the war of 1914-18 did really strong optical industries spring into being in Great Britain and the United States. The sudden demand for optical instruments of all kinds in Australia in the early part of the war of 1939-45 constituted what was, up to that time, probably one of the most exacting of the demands made on the scientific and manufacturing resources of the country.

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[1] J. A. Borkin and C. A. Welsh, *Germany's Master Plan: The Story of an Industrial Offensive*, London (1943).

[2] Before the second world war optical glass was manufactured in Britain, Germany, France, the United States, Italy and Japan.

Men with experience in the manufacture of optical instruments were amazingly few. At the highest level, on the theory and design as well as on the practical side of optical instrument making, the Munitions Supply Laboratories had on their staff only one man with considerable experience, and that was Mr Esserman whose experience had been gained in the older optical centres, more especially those of Britain, towards the end of the first world war. In 1918 Mr A. E. Leighton had suggested to Mr Esserman that Australia should start building up an optical industry in order to avoid dependence on oversea sources of supply.[3] Acting on this advice Esserman took courses on the theory and design of optical instruments at the Northampton Institute and at the Imperial College, London, which housed the first Department of Applied Optics established outside Germany. In both places Esserman studied under men of the highest reputation and experience in optics. On completing his studies he returned to Australia to take up a position in the Munitions Supply Laboratories, of which he later became Assistant Superintendent. In this capacity he supervised the repair of optical instruments for the army, designed modifications of certain short-base range-finders, and worked on the problem of fitting graticules to binoculars.

The first world war has, from a scientific point of view, often been called a "chemists' war" and the second world war a "physicists' war". Whatever the truth of these generalisations, it is certain that during the late nineteen-thirties physicists in universities and other research institutions of Great Britain and Australia foresaw that they were likely to play an important part in any future conflict and were not only on the alert but in many instances actively engaged in investigations likely to be of use in war, some time before its outbreak.

Early in August 1939, for example, members of the Australian Branch of the Institute of Physics, recognising that they might soon be called upon to do work of importance in national defence, met in Melbourne to consider possible courses of action. One result of their deliberations was a letter to the Prime Minister, Mr Menzies, from the President of the institute, Professor Laby, and the Secretary, Professor Ross, suggesting that a consultative committee should be set up to advise the Government on matters relating to physics. Though the Prime Minister expressed his appreciation of the institute's offer, little came of it for some time. At a meeting held soon after the outbreak of war between the officers of the Institute of Physics and the Department of Supply and Development, a government spokesman stated that "while foreseen developments were well provided for, new developments might arise at any moment and the discussion had indicated lines on which immediate action could be taken as occasion demanded". The new developments followed some months later, when in June 1940 Australia was thrown almost entirely on her own resources. When the Directorate of Ordnance Production first embarked on the manufacture of the 2-pounder anti-tank gun the intention was to

[3] Australia's peacetime requirements of optical instruments were valued at about £750,000.

rely on the United Kingdom for the necessary optical equipment; similar plans had been made for the 25-pounder and the 3.7-inch anti-aircraft guns. These arrangements were no longer practicable. The inability of Britain and the United States to supply any optical equipment whatever caused grave anxiety, for without telescopic sights these guns could not be accurately aimed except at point-blank range. Faced with this crisis, the Director of Ordnance Production, Mr Hartnett, called the physicists together on 26th June 1940 to discuss the possibility of making sighting telescopes and dial sights in Australia.

The meeting led to the formation of a body initially called the Optical Munitions Panel, a title later changed to the Scientific Instruments and Optical Panel. At the time of its formation there was no single centralised research institution in the Commonwealth capable of advising the Department of Munitions on all the intricate problems likely to arise in any attempt to make optical instruments. It is true, a beginning had been made at the Munitions Supply Laboratories to study the problems of manufacture of telescopes, but the task that lay before the country was much too complicated and extensive to be undertaken with the resources of those laboratories alone. The position in regard to the possibilities of manufacture was much the same as in the case of aircraft and torpedoes. Facilities or potential facilities lay scattered throughout the main cities of the Commonwealth—in laboratories, observatories and in spectacle and glass factories. There was no time to set up a single optical manufacturing centre. In spite of the fact that it might call for an immense amount of coordination of effort, it was a much more economical procedure to use men and machines wherever they were to be found. The principal task of the panel was to advise the Directorate of Ordnance Production on the scientific and technical problems likely to arise in making optical munitions and also to give assistance to firms and annexes selected or established for their manufacture. Membership of the panel, which first met on 23rd July 1940, was as follows:

Prof T. H. Laby (Chairman)
Lt-Col G. H. Adams[4]
F. S. Daley
N. A. Esserman
Prof Kerr Grant[5]
L. J. Hartnett
Assoc Prof E. O. Hercus[6]
E. L. Sayce[7]
Prof O. U. Vonwiller[8]
Dr R. v.d.R. Woolley[9]
J. S. Rogers[1] (Secretary).

[4] Col G. H. Adams, MC, ED. (Served 1st AIF.) Asst Director of Artillery AHQ, 1940-42. Wine merchant; of Melbourne; b. Melbourne, 19 Jun 1886.

[5] Sir Kerr Grant, MSc. Prof of Physics, Univ of Adelaide, 1911-48. B. Bacchus Marsh, Vic, 10 Jun 1878.

[6] E. O. Hercus, DSc. (Served RNVR 1916-18.) Assoc Prof of Physics, Univ of Melbourne, since 1931. B. Dunedin, NZ, 23 Jun 1891.

[7] E. L. Sayce. Assistant Superintendent, Munitions Supply Laboratories, 1939-52. Of Melbourne; b. Hawthorn, Vic, 20 Dec 1899.

[8] O. U. Vonwiller, BSc. Prof of Physics, Univ of Sydney, 1923-46. B. Sydney, 18 Feb 1882.

[9] R. v.d.R. Woolley, OBE; FRS, MSc, MA, PhD. C'wealth Astronomer 1939-55; Chief Executive Officer, Army Inventions Directorate, 1942-45; Astronomer Royal, Greenwich, Eng, since 1955. B. Weymouth, Eng, 24 Apr 1906.

[1] J. S. Rogers, MC; BA, DSc. (Served 1st AIF.) Senior Lecturer in Physics, Univ of Melbourne, 1924-46. Warden, Mildura Branch, 1946-50, Dean of Graduate Studies since 1950. B. Beaconsfield, Tas, 18 Jun 1893.

The panel was enlarged from time to time. Members were drawn from all parts of the Commonwealth: from government laboratories such as Munitions Supply, National Standards and the Commonwealth Solar Observatory; from the armed forces, and from the physics departments of the Australian universities. All university members except the secretary served in an honorary capacity; the secretary was paid by the University of Melbourne throughout the tenure of his office and received a small honorarium from the Commonwealth. Only two members of the panel had had any experience in the design and construction of optical instruments. Nevertheless, between them members of the panel possessed a reserve of fundamental scientific knowledge and skill, the existence of which was certainly not widely appreciated by the army or by industry until war came. Even then it was some time before the value of university departments of physics and government research laboratories was fully recognised.

Some idea of the magnitude of the work that had to be undertaken may be gathered from the fact that at the panel's second meeting Lieut-Colonel Adams submitted a list of urgently needed optical instruments estimated as being likely to cost more than £750,000.[2]

Priority	Instrument	No. required
1	Sighting telescope 24B	3,500
2	Height and range finder OB7	65
	Ring Sight telescope	83
	Identification telescope	86
	Dial sight No. 7	1,500
	Director No. 12	2,500
	Spirit Levels of various kinds	3,000
3	Signalling telescopes	1,200
	Range-finders No. 13	265
	Binoculars No. 2	3,500
	Stereoscopes	250
	Parallax bars	50

This was a formidable program indeed for a country with no optical industry, for up to this time, apart from spectacles made from imported glass, not a single optical instrument worthy of the name had ever been manufactured on a commercial scale in Australia.

Soon after its formation the Director-General of Munitions, Mr Essington Lewis, asked the panel for "a comprehensive report on the cost and problem of producing optical munitions in Australia". The report was drawn up by the chairman and secretary, was submitted to Hartnett, and sent on to Mr Essington Lewis on 23rd August 1940. The report was most emphatic that great difficulties lay ahead. These anticipated difficulties were threefold: 1. no optical glass suitable for making the lenses and prisms needed for telescopes and other optical instruments was being made in Australia; 2. there were few, if any, workers with experience in grinding and polishing glass lenses and prisms to the accuracy essential in optical

[2] This estimate was made in the "Report on Cost and Production of Optical Munitions" to the Director-General of Munitions by the Chairman of the Optical Munitions Panel.

instruments; 3. there was a serious shortage of instrument makers needed for making the very accurate metal parts of optical instruments. Military optical instruments required metal parts made to a high precision—at least as high as that demanded of instruments for physics, astronomy and surveying. The panel's report listed the tolerances or errors permitted in producing flat or curved surfaces in different kinds of work, as giving some idea of the level of accuracy and skill that would be called for. (These tolerances are shown in the accompanying table.)

Trade	Error permissible along 1 inch of surface
Engineering	1,000th of 1 inch
Aircraft	10,000th „ „ „
Spectacle making . . .	10,000th „ „ „
Highest quality optical . .	1,000,000th „ „ „

However, optical munitions were so urgently needed that the War Cabinet decided in spite of the pessimism of the report that their manufacture should be undertaken forthwith. This involved three distinct stages:

1. making lenses and prisms;
2. making metal parts to hold the lenses and prisms;
3. assembling glass and metal parts and testing the completed instruments.

That there would be difficulties everyone concerned agreed, but curiously enough no one anticipated the stage that was to offer the most serious obstacle.

It was obvious that before any progress could be made with the first stage adequate supplies of optical glass must be obtained. The importance of this part of the program may be gathered from a comment by an American scientist in the first world war:

> Military fire control apparatus includes instruments of high precision, and as one of the integral parts of such instruments optical glass must measure up to the same high standards of precision. Upon it the quality of the image formed and the precision of each setting of the sighting instrument is dependent. The lens designer computes the shapes and positions of the several different lenses and prisms in an optical instrument and arranges them along the line of sight in such a way that the particular and inevitable defects or aberrations are reduced to a minimum. The degree to which these aberrations can be made negligible depends in large measure on the kinds and quality of the glass available to the designer. It is important therefore that the quality of the glass be of the best and that a sufficient number of different types be at hand.[3]

Glass of this quality had not previously been made in Australia, or indeed anywhere outside Europe and North America. At first, as a temporary expedient, efforts were made to substitute glass of the quality used in spectacle lenses, and some telescopes were actually made with this kind of glass.

Orders for glass had been placed in Britain and the United States but it soon became evident that these countries could not be relied upon to

[3] F. E. Wright, *The Manufacture of Optical Glass and Optical Systems*. Ordnance Dept Document 203, Washington, Govt Printing Office (1921).

spare sufficient from their needs to meet Australia's requirements. The United States was at this period suffering from a "glass famine". As it seemed quite likely that Australia might soon be cut off from oversea supplies altogether, Hartnett convinced the panel that the manufacture of optical glass should be undertaken in Australia immediately. Some preliminary steps had already been taken by Adams, who on 25th June 1940 had sounded Australian Consolidated Industries on the possibility of their making optical glass. This company, the only glass manufacturing firm in Australia, was asked to consider the matter from "a purely national point of view" and "in case of possible emergency". Its response was prompt and entirely favourable.

The art of making optical glass consisted of melting together certain ingredients to form a molten mass sufficiently fluid to be readily and thoroughly stirred.[4] Almost the entire process centred on procedures designed to ensure that the glass was perfectly homogeneous, free from bubbles and flaws, and of exactly the desired optical properties; only thus could the necessary perfection of its optical behaviour be attained. Though this may sound simple, in practice it called for the highest degree of control and skill. Chemical purity of the raw materials, especially freedom from traces of iron and titanium, was essential if the glass was to be colourless and highly transparent.

When the United States entered the war in 1917 she found herself in the very serious position of being almost entirely without an optical glass industry. It is worth recalling briefly how these difficulties were overcome, because of the influence her success was to have on Australia's fortunes some thirty years later. For a long time much of the technical detail of glassmaking was a closely guarded secret. The seizure of patents did not help greatly to break down these secrets. In 1917 America was fortunate in having at the Geophysical Laboratories of the Carnegie Institute of Washington a team of highly skilled scientists who had been studying molten materials similar to optical glass. Their work, directed in the first instance to purely academic studies of rock-forming minerals, paid handsome dividends when the knowledge so gained was applied to the problem of making optical glass. The Americans were highly successful in producing optical glass, though they did not succeed in producing all their requirements. Nevertheless, mainly on account of the shrinking demand, America allowed her optical glass industry to decline after the war of 1914-18, except in two important centres. One of these, the Bureau of Standards at Washington, D.C., carried on vitally important research and small-scale production throughout the period between the wars.

One of the first committees set up by the Scientific Instruments and Optical Panel was the Advisory Committee on Optical Materials under the

[4] The ingredients used depended upon the kind of glass required. They included silica (sand) and the oxides of such metals as sodium, potassium, calcium and aluminium. In addition to the oxides of these metals certain other oxides were used to impart special properties. These included oxides of lead, zinc, barium, arsenic and boron.

chairmanship of Professor Hartung[7] of Melbourne. Besides his purely chemical interests, Hartung had long been deeply interested in optical instruments and during his travels abroad had made short visits to the optical glass factories of Zeiss at Jena and Chance Brothers at Smethwick. Having kept a diary of these visits he was aware in a general way of what was involved, chemically at all events, in the manufacture of optical glass.

The Advisory Committee met early in August 1940 and laid down a general plan of procedure, as a result of which Hartung went to Sydney to consult with the technical staff of Australian Consolidated Industries Ltd.[8] A plan of joint work with the Chemistry Department of the University of Melbourne was agreed upon. Through the help of A.C.I., which furnished advice and essential equipment, a small gas-fired furnace was built in the department and experimental work was in full swing in October 1940.

The basic raw materials not only of the glass but also of the pots in which it was melted varied slightly from one source to another. For example, no batch of sand was perfectly pure silicon dioxide; the impurities present in any batch depended on the source or deposit from which it was derived. Some impurities had a deleterious effect on the glass, others had little or no effect. The suitability of a raw material could be satisfactorily determined only by actual trials. There were therefore two preliminary problems: the suitability of Australian raw materials for the production of the glass, and the suitability of Australian clays for the glass pots. By close cooperation between A.C.I. who selected the clays and made small experimental pots, and the Chemistry Department of the university, whose staff undertook experimental meltings of various glass batches in these pots and subsequent examination of the glasses produced, both problems were solved in the laboratory by about the middle of 1941.

Translation of a small-scale operation to the large scale was seldom just a problem of simple magnification of the operations. Troubles might arise on the large scale which were not encountered in the laboratory. It was difficult, if not impossible, to learn scientific and technological processes from books and the patent literature alone. This was especially true if time was important—as it was then. In the transmission of scientific and industrial techniques from Europe and America to Australia, gaining of direct experience was usually the crucial step.

Since Australian Consolidated Industries did not have any men with experience in the manufacture of optical glass, it was clear they had either to import such a man or men, or send their own men overseas for training. One of their first actions was to approach, through their London representative, the firm of Chance Brothers for help. It was learned that Chance Brothers could not make even one skilled man available. All their

[7] E. J. Hartung, DSc. Lecturer and demonstrator in Chemistry, Univ of Melbourne 1919, Prof 1928-53. B. Melbourne, 23 Apr 1893.

[8] In particular with the technical manager Mr H. J. Quinn, and the chief chemist Mr J. S. Blakeney.

resources were taxed to the utmost, not only with their main works but with a shadow factory designed to replace the main one if it were bombed out of action. They were also busy with an extension of their activities to Canada.

Representatives of Australian Consolidated Industries in London then attempted to reach an agreement with Chance Brothers whereby the Australian firm could send men to England for training and at the same time obtain drawings of plant and equipment and details of the latest developments in the process for making optical glass. While these negotiations were going on (towards the end of 1940) a meeting was held in London of representatives from the Admiralty, the Canadian and Australian Governments, Chance Brothers, and Australian Consolidated Industries. It was suggested that Australia might cooperate with Canada and thereby make it unnecessary to establish the manufacture of optical glass here. Canada, it was said, was then in the course of establishing, with the help of Chance Brothers, a government factory to be known as Research Enterprises Ltd, for the manufacture of optical munitions. This plant when completed would have the advantage of proximity to one of the largest arsenals in the world and access to the great technological help that could be given by the United States. Chance Brothers expressed the view that, "having regard to the problems of chemical and physical control as well as the highly complicated details therein involved, Australian glass makers may be under-estimating the difficulties they have to face".[9] The Australian High Commissioner in London, Mr Bruce, summed up the position in a cable which read: "Have conferred with Admiralty and Chance Brothers very emphatic that the making of optical glass in Australia would be wasteful of war effort as it would probably take four years before a successful production could be achieved and the cost would probably be a million pounds accordingly they discourage. . . ."

When these suggestions were communicated to the Optical Panel, its immediate reaction was to pass a unanimous resolution recommending that the manufacture of optical glass in Australia should be undertaken forthwith. The Government, actuated partly by this recommendation and possibly even more strongly by suspicions about Japanese intentions in the Pacific, gave Australian Consolidated Industries instructions to go ahead with the project. The company made one more effort to get help from Chance Brothers, but the terms imposed, including royalties and post-war restrictions to be placed on any Australian optical glass industry that might grow up, were not acceptable. A.C.I. therefore decided to go ahead in its own way, finding out details of the process, securing the necessary plant, and training men for the job.

The Australian glass industry had one thing in its favour which should be mentioned: like the steel industry, it was highly integrated. Whereas in other parts of the world firms specialised in making one or two kinds of glassware, Australian Consolidated Industries made a very wide range.

[9] J. S. Rogers, "History of the Scientific Instruments and Optical Panel" (unpublished), to which I am indebted for much of the information contained in this chapter.

Its experience in making crystal glassware proved especially useful. Glass for crystal ware had to be as nearly colourless as it was possible to make it, but otherwise the requirements were no more exacting than those for ordinary glass. An important advantage accruing from the company's wide experience in glass manufacture was that it had, in the course of years, made a thorough survey of the local supplies of raw material for the industry. It still had to learn how to make optically homogeneous glass of any specified chemical composition. The next step was to agree to an arrangement whereby Mr Little,[1] a member of the technical staff, and Mr Grimwade,[2] appointed by the Department of Munitions, were sent by the Commonwealth Government to Canada and the United States. In view of the earlier negotiations and the Canadian firm's obligations to Chance Brothers, it is not surprising that their visit to Research Enterprises Ltd in Canada failed to lead to any agreement. Little and Grimwade then visited firms in the United States, including Bausch and Lomb, Spencer Lens, American Optical and Eastman Kodak, with no better success. All these firms were willing to allow them to make an inspection of the factories of the kind offered to tourists, but nothing more. When one bears in mind the earlier failure to reach an agreement with Chance Brothers it is difficult to understand now why the Australian company should have expected to learn details without cost from the private American firms. It reported that its representatives spent three weeks "running everywhere into a brick wall of secrecy".[3]

After this unbroken succession of failures, Little and Grimwade almost gave up the idea of visiting the National Bureau of Standards which, they believed, was merely engaged on experimental work. As events proved, nothing was further from the truth. Far from being unable to give advice to industry, they found "the National Bureau of Standards particularly well fitted to render such service inasmuch as it is the only scientific institution in the world which has, entirely within its own organisation, complete facilities for making an optical instrument beginning with the raw materials and producing in turn the glass, the optical design, lenses and prisms, the mechanical parts and finally the finished instruments".[4] Moreover, during the years between the wars the bureau had conducted extensive series of investigations on the relation between the optical behaviour of glass and its chemical composition—investigations which were published in great detail in its *Journal of Research* and were of considerable help to makers of optical munitions. Much of the veil of secrecy that before the first world war had surrounded optical glass making, was lifted by the National Bureau of Standards. There is no doubt that the help so freely given by members of the staff of the bureau to Grimwade and Little and to

[1] H. G. Little. Factory Chemist, Aust Window Glass Pty Ltd. Of Sydney; b. Sydney, 15 Nov 1915.
[2] G. H. Grimwade, MA, BSc. Company director. Of Toorak, Vic; b. Melbourne, 19 Sep 1902.
[3] "The Industrial War Effort of Australian Consolidated Industries Limited, 1939-45."
[4] *Research and Development in Applied Optic and Optical Glass at the National Bureau of Standards.* Miscellaneous Publications 194 (1949).

others who came later (Dr Briggs and Mr Giovanelli[5] of the National Standards Laboratory, and Mr Rogers, Secretary of the Optical Panel) proved of the utmost value. For this Australia owes the bureau a debt of gratitude. The reception given to its representative is described in a report by Australian Consolidated Industries:

> . . . the officials of the Bureau did everything in their power to provide him with data required. Their plant was thrown open to him for detailed examination; details of glass composition, batch formulae [lists of materials and their proportions that are melted together to form glass], pot making technique, moulding procedure, methods of inspection, annealing—nothing was withheld. Here then the Australian was able to check and verify Australian Consolidated Industries' blue prints of plants, processes and techniques which he had carried with him from Australia.

These were tentative plans based on the company's own experience and information from Wright's book. The company did not follow exactly the American practices but where necessary adapted them to local conditions, and succeeded in establishing for the Directorate of Ordnance Production a well-designed annexe at Australian Window Glass Pty Ltd, a subsidiary company of Australian Consolidated Industries.

The company's enterprise over many years had brought to light excellent sources of raw materials. A remarkably good supply of silica (sand) was procured from the aeolian deposits at Botany, Sydney—literally at the company's back door. After processing, this sand was considered to be one of the purest glass-making materials available anywhere in the world. Other materials were gathered from all over the Commonwealth: extremely pure calcite (to provide lime or calcium oxide) from George's Plains near Bathurst, New South Wales; zinc oxide (from Tasmania), lead oxide (from Port Pirie lead), soda ash (from Imperial Chemical Industries' plant at Osborne, South Australia). Borax and boric acid (from the United States), hydrated alumina and potassium nitrate (from the United Kingdom) were the only materials that came from outside Australia. Fortunately the company had accumulated substantial stocks of these materials before the outbreak of war.

It was quite a straightforward matter to make up accurately-proportioned mixtures of these pure materials, but it was another matter to finish up with a glass of exactly the desired composition. At the unusually high temperatures needed to secure fluidity of the molten glass (about 1,500 degrees centigrade) some of the ingredients were lost by being volatilised. Another difficulty, caused by the greatly enhanced chemical activity of substances at high temperatures, was to prevent the molten glass becoming contaminated with substances from the walls of the clay pot in which it was being heated. For this reason it was essential to have clay pots made of refractory material that would introduce a minimum of foreign matter into the glass. Not only had the refractories to be free from undesirable

[5] R. G. Giovanelli, DSc. Teacher of Physics, Sydney Technical College, to 1940; Research officer, National Standards Lab, since 1941. Of Sydney; b. Grafton, NSW, 30 Apr 1915.

impurities such as iron, they had also to have the necessary strength and the ability to withstand continuous heating for at least 24 hours at 1,500 degrees centigrade. Contamination was more likely to arise in making optical than any other kind of glass, because the proportion of molten glass exposed to contamination from the walls of the pot was much greater.[6] Success in the manufacture of optical glass depended to a very large extent on the quality of the melting pots.

More than 100 different clays which over the years had been collected from as far afield as Goulburn, Lake Macquarie, and Wellington, New South Wales, were tested and eventually a suitable one was found. Fabricating the pot itself called for experience and skill. In the early days of optical glass making, such pots had been made by hand and required a long time for drying—upwards of nine months in the usual process. During the 1914-18 war a method for manufacturing pots known as slip-casting was devised at the National Bureau of Standards. This method was now well known to the Australian glass industry, which had been using it for several years to manufacture special parts of ordinary glass furnaces. In slip casting, clay of the consistency of porridge was poured into a special porous mould and because of this a greatly reduced time for drying was required. The successful solution of the problems relating to the manufacture of clay pots owed much to Mr Death,[7] the expert in refractories at A.C.I. But the difficulties were not all over with the solving of the problems of pot making.

To make the glass, a pot was charged with about half a ton of mixture, placed in a furnace and slowly brought up to a temperature of 1,500 degrees centigrade. While at this high temperature the melt was stirred mechanically by means of a clay rod. After the molten mass had been made as homogeneous as possible, the pot and its contents were allowed to cool very slowly. Controlled cooling to room temperature took anything up to 96 hours. After the pot and its contents had cooled, the mass of glass was broken up into chunks of different sizes, care being taken not to shatter the glass unduly. The chunks were then critically examined for imperfections, such as bubbles and striations due to inhomogeneity of the glass. Those that passed the test were carefully reheated, picked up on an iron rod, and transferred to a clean metal surface where they were patted and rolled like dough. Inclusions or folds were then snipped out and when the glass was of approximately the right shape, and while it was still plastic, it was cut to fit closely into the moulds designed for the particular component and pressed into shape. Finally the glass was annealed. Here again American help, in the form of instruments capable of automatically controlling the heating and cooling to predetermined time schedules, was invaluable.

No glass was ever entirely free from mechanical strains which destroyed its optical homogeneity. For optical work these strains, which must be

[6] Ordinary glass was made in much larger tanks, rectangular in shape.

[7] C. W. Death. Works Manager ACI Refractories Pty Ltd 1932-46. Chemist; of Sydney; b. Fordham, Essex, Eng, 15 Nov 1901.

reduced to a minimum, were released by taking the glass up to a temperature just short of its softening point, and then allowing it to cool very slowly over about six days. The rate of cooling depended upon the size of the piece of glass: for the glass in a large astronomical reflector such as the 200-inch, a period of up to six months might be required for annealing.

As can easily be imagined, many of these operations called for experience and skill. Although at the outset the Australian company did not have a single man trained in optical glass processes and, it will be recalled, failed in negotiations to have any of its men trained overseas, no trained men were imported. In the event, it relied entirely on its own men and experience and the details learned by Little at the Bureau of Standards. American experience in the first world war had been that it was extremely difficult for men who had been trained in the production of plate glass, for example, to turn to the production of optical glass. The Australian effort was made by men whose main advantage was experience in the making of lead glass for crystal ware. There were relatively few even of these. As so often happened during the war, whatever totally unskilled labour happened to be available had to be brought in and trained for the job. This was done successfully, and on 21st September 1941 Australian Consolidated Industries produced the first large-scale batch of optical glass ever to be made in Australia.

This first melt, a borosilicate crown glass, passed all the stringent tests laid down by the army authorities. Most of the accurate measurement and testing of the optical properties of the glass, such as refractive index and dispersion, were carried out by the Physics Section of the National Standards Laboratory. The refractive index of the first melt was within 0.002 of the required figure, whereas specifications allowed a tolerance of 0.003. So it was that, by the time the Pacific war began, Australia had an assured supply of optical glass adequate to meet all the demands of the armed forces.[8] In spite of a late start she was only one month behind Canadian Research Enterprises Ltd. Production was achieved within about ten months of the decision to undertake it—instead of the predicted four years—and at a cost of about £60,000 instead of the predicted £1,000,000.

The supply of glass was adequate both in amount and in variety. Within six months of the first output the production of five standard types of optical glass had been perfected. In all some thirteen different kinds of glass were made, including several special coloured glasses for protecting the eyes against glare, and for conditioning them to seeing in the dark, as will be described later. The company claimed that by improving existing techniques the yield of glass was increased from the 12 per cent customary in oversea commercial practice to the extraordinary figure of 17 per cent. The extent of its output is indicated in the following table

[8] Except for the dense barium crown variety, which was never successfully produced during the war.

showing the number of blanks produced. (Blanks were lenses and prisms moulded roughly to the required final shape.)

Tank periscopes	10,000
Dial sights	68,000
Anti-tank gun sights	46,000
Rifle sights	39,000
Cruiser-tank gun sights	15,600
Naval gun sighting telescope	8,600
Anti-aircraft predictors	8,400
Aircraft identification telescope	3,300

A large amount of glass was supplied to forces other than Australian:

U.S.A. (blanks for dial sights)	57,000
N.Z. (various components)	4,700
India (slab glass)	5,200 lb.

Specimens of every melt of glass were tested in the Physics Section of the National Standards Laboratory, of which Dr Briggs was Officer-in-Charge. With most types of glass a very high degree of constancy of refractive index from melt to melt was achieved. For example, the greatest variation of the refractive index of eight melts of borosilicate crown glass from the average value of 1.51000 was 0.002. Some glasses were more successfully reproduced from melt to melt; others were not so well reproduced. By and large the reproducibility was satisfactory. Efficiency of annealing was also tested at the National Standards Laboratories with similar satisfactory results. Exacting tests, made to determine the degree of homogeneity, also showed that the glass was generally of a high quality. The verdict of the British Scientific Instrument Association given as a result of tests carried out at the request of the Admiralty, substantiates these statements: "All the specimens showed freedom from veins and other defects of this type. These specimens of Australian optical glass are in general of first class quality and the telescopic flint and borosilicate glasses are very good indeed."

Like many another wartime achievement, the making of optical glass was the result of good team work. Special mention should be made of Mr Warren[9] and Mr Blakeney,[1] but to do justice it would be necessary to name all members of the technical staff of Australian Window Glass.

Having arranged for the production of adequate amounts of suitable glasses, the Directorate of Ordnance Production was ready to proceed to the next step: the manufacture of optical components, principally lenses and prisms.[2] The shapes and sizes of these were either given in specifications or, where entirely new instruments were required, they had to be calculated. Once size and shape were known, the blanks supplied by Australian Consolidated Industries had to be ground and polished to exactly those requirements.

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[9] A. W. Warren. Chemical engineer with ACI to 1941; in charge of Optical Glass Annexe 1941-46; Works Manager ACI Refractories since 1946. B. Goulburn, NSW, 2 Jun 1919.

[1] J. S. Blakeney. Works Chemist, Aust Glass Manufacturers Pty Ltd, to 1940; Chief Chemist ACI 1940-48, Works Manager since 1948. Of Sydney; b. Sydney, 26 Feb 1915.

[2] Some glass was imported, but it was only a small fraction of requirements.

Men with experience and skill in grinding and polishing glass to the accuracy required for instruments of high precision were very few indeed. The Commonwealth Solar Observatory was fortunate in having the services of Mr Lord,[3] who had studied in Paris under Professor Fabry and had had practical experience in Czechoslovakia, and also of Mr Elwin,[4] an amateur astronomer with much experience in optical glass working. Both men gave instructional courses, Lord on elements of optical computing, and Elwin on techniques of glass working. At the University of Melbourne Mr Dainty,[5] who had gained considerable experience in grinding and polishing lens prisms in England some years before, gave much assistance in developing these techniques; he had in fact come to Australia from New Zealand for this purpose.

In January 1940 the Munitions Supply Laboratories sent Mr McNeil[6] to England to undergo a two-year course in optical design. McNeil found private manufacturers of optical instruments in England most cooperative —more so than the glass makers—and on his return in 1942 gave a considerable impetus to optical design. Towards the end of 1941 the same laboratories were able to arrange with Adam Hilger Ltd, a leading British firm making optical instruments, for the loan of a highly skilled glass worker who would establish workshop practice on a sound footing. He arrived early in 1942 and his assistance in the development of methods for making high-quality glass prisms and plane parallel glass plate, and in training men in these methods, was particularly valuable.

Lenses and prisms were for the most part made by men and women whose previous experience was limited to the much less exacting work of making spectacle lenses. The kind of polishing used for spectacle lenses did not lead to a sufficiently accurate surface, nor did the spectacle maker use test-plates and optical interference fringes to check his work. Entirely new techniques of pitch polishing (in place of felt polishing) and of lens testing had to be learned. By means of classes conducted at the Sydney and Melbourne Technical Colleges, together with the help of the Commonwealth Solar Observatory, the annexe at Hobart, and the Munitions Supply Laboratories, spectacle-lens workers and others were trained to the level of skill required. On the whole, employment of men with experience in spectacle-lens work was found to be satisfactory, there being very few who did not show some aptitude for the higher grade work. This was contrary to the experience in Great Britain during the first world war, where the same experiment did not work out at all satisfactorily. At least one firm in Australia decided to train women without any previous experience in glass work, and obtained excellent results.

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[3] F. Lord. Optical engineer in Prague 1936-39; Officer in Charge Optical Workshop C'wealth Observatory, 1940-45. Of Prague; b. Opava, Czechoslovakia, 16 Sep 1916.

[4] S. J. Elwin, MSc. Lecturer in manual training, Sydney Teachers' College, till 1939; Lecturer in Physics at Technical College, then at Teachers' College. Of Sydney; b. Sunderland, Eng, 11 Feb 1906.

[5] G. F. Dainty. Optical technician, Barr and Stroud, England, then at Univ of Melbourne. Of Christchurch, NZ; b. Birmingham, Eng, 20 Oct 1887.

[6] J. J. McNeil, MSc. Physicist with Munitions Supply Labs (Optics), later with CSIRO. Of Melbourne; b. Ballarat, Vic, 17 Sep 1916.

The techniques of designing and manufacturing optical instruments were also being developed in the Physics Section of the National Standards Laboratory under Dr Briggs. The program included setting up facilities for the design, construction, analysis and test of optical instruments. Machines for optical lens making had been ordered in 1939 and an optical shop under Mr Schaefer[7] was in operation by August 1941 for the production of lenses, prisms and other optical components. An example of its work was the design and production in large numbers of a four-component lens system for the lumi-gauge, an optical gauging instrument.

Once the lenses and prisms had been made it was necessary to have metal parts to hold and control their movements. Provision of these demanded mechanical construction of the highest accuracy. Skilled mechanics who could make the parts with adequate precision were rare, and considerable trouble was experienced in this phase of the work. Here was revealed a grave deficiency in Australia's resources of skilled manpower and the cause of one of the most serious bottlenecks in producing optical munitions. There was also a scarcity of optical adjusters—men who assembled and adjusted the optical components in the mechanical framework. At the outbreak of war only one man in Australia was found who had had experience of this kind of work,[8] though many were trained later. Shortage of skilled mechanics and optical adjusters led the Optical Panel to advocate "that Australia in peacetime should maintain either in private industry or in Government workshops sufficient highly trained mechanics and instrument assemblers so that should the occasion again demand the rapid production of optical munitions there will not be the exasperating delays . . . which occurred" in the second world war.

The difficulties were accentuated by the general shortage of machine tools. At first certain instruments could not be made because contracting firms were unable to turn out metal structures with sufficient accuracy. The readings of a director, for example, had to be accurate to within two minutes of arc, a degree of precision called for only in high-grade scientific instruments, such as a surveyor's theodolite. After a great effort, for other industries were competing for the limited numbers of skilled men, enough were found in firms making wireless equipment, jewellery, totalisator equipment, typewriter accessories, and in all kinds of small engineering establishments, to carry through the work.

Similar troubles were experienced in finding men capable of assembling all the parts to make the complete instrument. Contracting firms entrusted with the work had had no experience in the assembling of instruments and were often without the necessary testing devices, such as collimators. Here the cooperating laboratories—the university physics departments and the different government laboratories—did excellent work in training instrument assemblers, lending suitable testing instruments, and helping

[7] V. R. Schaefer. Textile worker and amateur astronomer. Glass worker and technical officer, National Standards Laboratory, 1941-51. B. 19 Apr 1915. Died Jan 1951.

[8] This was Mr C. Halliday, who had received his training at the well-known British firm of Barr and Stroud.

to devise methods for attacking various problems. At first firms were sceptical of the ability of scientists from university and government laboratories to help in solving their problems, but eventually they became fully convinced.

In November 1939 practically the only machines capable of fashioning optical glass into accurate lenses and prisms were an odd assortment of grinding, polishing, edging and disc-cutting machines at Maribyrnong Supply Laboratories. Some machines arrived from England early in 1941, but the rest were made in Australia. The Australian Optical Company Ltd, which came to be the largest manufacturer of optical munitions, made all its own machines. After many attempts the company's chief engineer succeeded in designing a machine which could grind lenses to the required accuracy. Then in association with others he designed a lens-blocking machine which simplified this intricate and important operation so greatly that unskilled and semi-skilled workers were able to produce many thousands of precision lenses each month.

Several excellent glass-working machines were designed and built in the Optical Annexe at Hobart.[9] There also the technique of using diamond dust in glass roughing and grinding was developed. Diamond dust mixed with dental amalgam was used in glass-cutting saws. In fact "the whole trend at Hobart was to treat glass grinding as if it was metal grinding and some of the glass grinders were just milling machines in which the glass was held in ingeniously designed jigs".[1] Many diamond dust saws were later made at the University of Melbourne. Similar advances were made simultaneously but independently in oversea laboratories.

Improvements in glass polishing that had been achieved overseas by the substitution of cerium oxide for rouge were quickly adopted in Australia. First introduced in Europe in 1933, its use spread to Canada and the United States in 1941 and thence to Australia. Substitution of cerium oxide was an important innovation because it reduced the polishing time to about half that required with rouge. At first imported Canadian cerium oxide was used, but it was not long before the Division of Industrial Chemistry, with its experience in the chemical treatment of monazite, discovered the technique of making a highly satisfactory cerium oxide-containing polishing powder and made the process available to a commercial firm.

Nearly all instruments classified as optical munitions were telescopes of one kind or another, or contained telescopes as part of their make up. This being so it was not surprising that the first military instrument to be made on a large scale in Australia was a telescope. Since the story of this instrument is a typical one in so far as the general plan of operations was concerned, it will be told in some detail. By no means the most com-

[9] The annexe was designed and built under the direction of Mr Eric Waterworth. It developed out of work on the manufacture of prisms and test plates carried out in the Physics Laboratory of the Univ of Tasmania.

[1] Rogers.

plicated instrument undertaken, it did, however, have difficulties of its own because no others had been made before.

The first instrument the army asked for was the Sighting Telescope 24B designed to be used either on guns, mounted in a tank, or on anti-tank guns. It was therefore likely to be required in fairly large numbers, 3,500 being asked for in the first instance. Drawings and specifications (originally drawn up by the British War Office), together with a specimen instrument, were sent by the Ordnance Production Directorate to the Optical Panel. Members of the panel studied the way in which the instrument was intended to be used, what kind of performance was expected of it, and how it could be produced with the materials available. Here the first obstacle was encountered. The War Office description of the telescope stated clearly enough the magnification and general performance to be expected but gave no information about the kind of optical glass used or the radii of curvature and thickness of the lenses used.[2] The information had to be obtained by measurements on the specimen instrument. This would have been straightforward enough had the right kinds of optical glass been available, but at the time no really suitable optical glass was to be had and there was no alternative but to make do with the crown and flint glasses used for spectacle lenses. This meant redesigning the instrument to the extent of recalculating the sizes, shapes and positions of the lenses, a task carried out by Woolley at the Commonwealth Solar Observatory. Owing to the fact that the only spectacle flint glass procurable was in the form of blanks smaller than those called for in the specifications, the instrument had to be modified still further.

A model of the modified instrument—Sighting Telescope No. 124 (Aust)—was made at the Commonwealth Solar Observatory, and submitted to the panel for critical examination. Having been accepted by the panel in October 1940 it was next sent on to the army for tests and trials. Here it failed to satisfy requirements for use in tanks but was good enough to function as an efficient aiming instrument in an anti-tank gun. The panel then prepared drawings and specifications which were sent on to the Directorate of Ordnance Production with a recommendation that an "educational order" be placed with each of two contractors. The directorate, after consulting with the Boards of Area Management in Victoria and New South Wales, decided to place orders with the British Optical Company (Sydney) and the Australian Optical Company (Melbourne), both of which had had previous experience only in making spectacles.

By February 1941 both contractors had produced their first sighting telescopes. In the opinion of the Optical Panel the instruments were still far from perfection but their performance was sufficiently promising to encourage the hope that the contractors, with a little more experience, might make really satisfactory instruments. At all events, the panel was

[2] "In this particular," said Rogers, "U.S. Army drawings are better than those of the War Office since they give full optical data for each optical component." A similar comment has been made on British and American drawings for aero-engines.

sufficiently optimistic to advise the Directorate of Ordnance Production to place an order at once for 1,000 instruments. This advice was taken.

One of the factors that handicapped the contractors in their first efforts to make the telescope was that they had no test plates for checking their lenses. After the Commonwealth Solar Observatory and other cooperating laboratories had come to their aid by making these gauges, they began to turn out satisfactory instruments, and by April 1942 some 900 telescopes had passed inspection. Rejections were very few indeed. Thus by the enthusiasm, ability and ingenuity of hundreds of men and women from many walks of life (for most workers had to be trained), the first military optical instruments in the history of Australia were produced. But their task was by no means over. Many other instruments, some much more difficult to make, were required. It would be impossible in reasonable compass to describe all the optical instruments made in this country during the next few years; they ranged from telescopes of all kinds, periscopes, range-finders, dial sights, parabolic searchlight reflectors, stereoscopes and bubbles (that is, spirit levels) to camera lenses. The procedures in the manufacture of each instrument were much the same.

Dial Sight No. 7, the second instrument in order of army priorities, was not only a complicated mechanical device but also complicated optically since it contained a telescope together with three prisms, two of which were roof prisms. These prisms had to be made with an accuracy that provided for error in aiming of no more than three minutes of arc. Here again lenses for the first instruments were made of spectacle glass but as soon as local optical glass became available the instrument was redesigned and became Dial Sight (Aust) Mark II.

In order to speed production of the mechanical parts of this instrument, an attempt was made to use the technique of die casting, a process in which a casting was formed by injecting molten alloy into a die under intense pressure. Castings made in this way reproduced the required dimensions to a high degree of accuracy, provided always that a suitable alloy was used. The attempt failed because the alloy chosen was not sufficiently stable or well produced. In other fields of activity die casting in Australia was a success, enabling the mass production of accurately formed metal objects that required no further machining. The failure in the manufacture of mechanical parts for the dial sight was not due to lack of zinc of the necessary 99.99 per cent purity for alloy making, since this grade of zinc was readily available from the Electrolytic Zinc Company at Risdon, Tasmania. Whatever the cause the fact remains that die casting for this work had to be abandoned. Ultimately the technique of making the metal parts of dial sights was mastered by J. W. Handley and Sons of Melbourne, and about 1,883 instruments complying fully with the specifications were made.

Range finder No. 13 was a really difficult instrument, especially in its mechanical parts, and the task was made even more difficult by the fact that no War Office drawings were available and the necessary information had to be obtained by measuring and analysing a specimen instrument. The first contractor chosen for this range-finder, even after he had been

given much technical assistance by the Munitions Supply Laboratories, failed to achieve the high standard of mechanical construction required. Eventually the contract was given to J. W. Handley and Sons, who, although they also encountered difficulties, did, by 1945, turn out range finders up to War Office specifications. By that time range finders were arriving from England.

Although searchlight mirrors were not the concern of the Optical Panel, it is appropriate to deal with them at this point. The first inquiries about the possibility of manufacturing them were made during August 1938, just before the Munich crisis. It was clear to the Australian Defence authorities that Britain would need all her resources and energy to put her own defences in order and that Australians must rely largely on their own efforts to meet their defence requirements. These were the considerations behind the exploratory inquiries made by the Royal Australian Engineers' establishment at George's Heights (Sydney) to Australian Consolidated Industries. In spite of these very early moves it was about three years before any mirrors were produced. The main reason for the long delay appears to have been the difficulty experienced by the company in obtaining sufficiently definite and satisfactory specifications to work upon and a clear idea of the number of mirrors actually required. The company's own story of the negotiations with the Department of Munitions gives the impression that the liaison between technical experts of the department and the company was not as satisfactory as it might have been. The company complained that the several successive specifications, obtained only after repeated inquiries on their part, were impossibly exacting and more appropriate to reflectors used in precision astronomical telescopes.[3] Some of the department's vagueness and hesitancy about the number of mirrors required appears to have been due to an uncertainty whether aluminium reflectors might not be more useful than glass ones because they would be relatively immune to destruction by machine-gun fire.

Until the end of the nineteenth century Germany had had a monopoly of the manufacture of searchlight mirrors. At the turn of the century Sir Charles Parsons, well known as a maker of astronomical telescopes and turbines, turned his attention to making searchlight mirrors. This he did so successfully that the firm of C. A. Parsons and Company of Newcastle-on-Tyne supplied more than 80 per cent of the reflectors used by the Allies during the first world war. It was substantially with Parsons' technique that mirrors were first made in Australia. After Australian Consolidated Industries had rejected the third specification sent in by the Department of Munitions, they had the good fortune to discover that Mr Coombes[4] of the Aeronautical Research Laboratory, Melbourne, had once been associated with C. A. Parsons and Company, and although he had

[3] "The Industrial War Effort of Australian Consolidated Industries Limited, 1939-45."

[4] L. P. Coombes, DFC; BSc. (Served RAF first world war.) Senr Scientific Officer, Air Ministry, 1924-38; Chief, Divn Aeronautics CSIR, 1938-48; Chief Supt of Aeronautical Research Lab, Dept of Supply and Develop, since 1949. B. Madras, India, 9 Apr 1899.

not actually worked on the manufacture of searchlight mirrors, he was acquainted with the Parsons process. In June 1940 the Department of Supply and Development lent Coombes to the company. Working with the aid of notes and sketches made largely from memory, he was able to give some indication of the process used in England. These notes were later supplemented by Dr Briggs, who about this time was visiting the works of Messrs C. A. Parsons Ltd to study optical problems associated with setting up the Physics Section of the National Standards Laboratory. While there he was shown round the mirror section. On his return to Australia he found much of what he had confidentially learned from the English firm as an officer of the C.S.I.R. would be of considerable help to Australian Consolidated Industries. The C.S.I.R. immediately explained the circumstances to Messrs C. A. Parsons, and the firm generously gave full approval to Briggs' passing on to the Australians whatever information he could.

At this stage the company met another obstacle, namely that of obtaining a satisfactory supply of glass for the mirrors. For a company making as much glass as Australian Consolidated Industries did this may sound rather strange, but searchlight mirrors called for plate glass, which was not made anywhere in Australia. Plate glass was first rolled or drawn into shape and then ground and polished to remove surface imperfections. To set up machinery for making plate glass in Australia would have been most expensive, and for a while it seemed that if plate glass had to be imported it might be as well to import the reflectors themselves. However this suggestion was rejected because greater space would be occupied by a cargo of reflectors and a much greater loss would follow enemy action against the ship carrying them. Orders for heat-resisting borosilicate plate glass were finally placed on 7th March 1941 with the firm of Pilkingtons in England.

The method of making a mirror was simply to bend a sheet of softened plate glass to approximately the required shape by allowing it to sag into a mould paraboloid in shape. Sagging was assisted by slightly reducing the air pressure within the mould. When cooled, the curved glass was taken from the mould, annealed, and then ground and polished. It was covered with a film of silver backed by a protective coat of paint, and finally baked at a temperature of about 230 degrees centigrade for four hours. By the time the heat-resistant borosilicate glass arrived from England (in October 1941) sufficient experimental work had been done to enable the company to begin production. The first mirror was tested and approved on 13th January 1942, at the School of Military Engineering, Liverpool. Within a month it had been despatched to Port Moresby.

Thus, despite the difficulties encountered over three years in obtaining adequate specifications; despite the heartbreaking struggle to obtain government authority to undertake the manufacturing process and the delays in obtaining the necessary borosilicate glass from England, within two months of Japan's entry into the war with its immediate threat to

Australia's north, the first of many Australian-produced reflectors was on its way to New Guinea. In all some 115 reflectors were made, every one of which satisfactorily passed army inspection.

An equally necessary searchlight component—the carbon rod used for forming the arc—was manufactured by Standard-Waygood Ltd of Sydney. For the graphite and cerium fluoride the firm relied upon imports, but the main ingredient, coke of a high degree of purity, was made from hard pitch supplied by the Australian Gas Light Company of Sydney. Altogether Standard-Waygood supplied more than 250,000 searchlight carbons.

Of the instruments made for the navy the most important was Naval Gun Sighting Telescope G.A.100, a copy of Royal Navy Instrument 353 A.H. With the help of several of the cooperating laboratories, the British Optical Company made about 450 of these telescopes.

The Optical Panel was able to assist with the production of instruments not directly connected with armaments; for example, lumi-gauge projectors designed to enable the assessment of the accuracy of screw threads and similar mechanisms. These projectors, the optical parts of which were designed in the National Standards Laboratory, were very helpful to makers of machine tools and gauges.

The success of the optical munitions program could never have been achieved without the help of government and university laboratories and departments, whose scientific resources it was the function of the Optical Panel to mobilise. Except in a few instances the laboratories were not involved in large-scale commercial production but this history would not be complete without some reference to them and to the successful way in which they worked together.

Since both the chairman and the secretary of the panel were members of the Department of Natural Philosophy in the University of Melbourne, this automatically came to be regarded as the panel's headquarters. Over many years there had grown up in the University of Melbourne, under Laby's inspiration, a very active school of research with a world-wide reputation. As soon as he became chairman of the Optical Panel, Laby directed that all research except that on optics and related fields should cease, and in this way a large team of physicists, including members of the staff and senior students, was ready to help the panel.

The work undertaken by his department was, like that of the Munitions Supply Laboratories, of an extraordinarily varied character. Being the headquarters of the panel, it was closely involved in a great deal of advisory work for contracting firms, for the Services, and for the panel itself. Small orders were accepted and executed for such specialised instruments as introscopes, spherometers, stereoscopes and telemicroscopes. It is in fact difficult to single out any activity as representing the laboratory's most important contribution. Not only did the members of the laboratory design and produce the prototypes of a great variety of instruments, they also undertook the analysis and testing of instruments and

tropic proofing. When Army Inspection became anxious to have all the optical parts of dial sights thoroughly tested, the members of the laboratory staff devised special methods based on interferometry for this purpose.

At the time when optical glass was very scarce and thousands of prisms were needed for tank periscopes, a technique for welding plate (crystalex) glass into solid blocks was worked out. Fortunately extensive use of this improvisation was not necessary because optical glass became available soon afterwards. An important use was, however, found for crystalex glass in Mosquito bombers: selected areas of the glass were sufficiently flat and homogeneous for use as windows through which aerial photographs might be taken.

An interesting process developed at the University of Melbourne was that of making mirrors by depositing films of aluminium on glass. The technique was not new: it had in fact been invented in the late 1930's by Dr John Strong of the California Institute of Technology, who used it in making reflectors for astronomical telescopes such as the 100-inch instrument at Mount Wilson and later the 200-inch telescope at Mount Palomar (California). Previously, metal reflecting films on glass had always been prepared by the chemical deposition of silver from aqueous solutions. Although the silvering process was not difficult to carry out, the resulting film suffered from a number of serious disadvantages in so far as it was soft and easily scratched and also highly susceptible to tarnishing. Deposition of a film of aluminium was more difficult because it had to be carried out under more exacting conditions in a high vacuum (less than one ten-thousandth of a millimetre of mercury). The object to be coated was placed in a specially built tank. The largest used in Melbourne was 40 inches in diameter. At some distance above the surface to be covered were placed a number of tungsten filaments that had been coated with aluminium. After the tank had been thoroughly evacuated by means of oil diffusion pumps, the tungsten filament was heated electrically to a sufficiently high temperature to melt and ultimately vaporise the aluminium. Atoms of aluminium were shot out from the heated filaments across the intervening vacuum, and if the filaments were correctly placed, deposited in an even, shining film on the surface being coated.

If it was necessary to make a mirror with a metal film on the front instead of on the back, aluminium became the metal of choice because its resistance to tarnishing was so much greater than that of silver. Exactly this situation arose when several thousand universal stereoscopes and hinged sighting telescopes had to be fitted with reflectors. These instruments were needed urgently, the stereoscopes for viewing aerial photographs and the hinged telescopes for use in tanks. The hinged telescope was designed for seeing round corners, a feat achieved by means of aluminised mirrors. Practically all the aluminium-coated mirrors needed were made in the Department of Natural Philosophy of the University of Melbourne.

Another important activity of the University of Melbourne was one in which the Departments of Botany and Chemistry collaborated with the

Department of Natural Philosophy. This was the problem of making graticules, which were required for practically every optical instrument used in the Services, except the signalling telescope. A graticule was a glass disc on which were inscribed measuring marks or scales to assist in the determination of the size, distance, direction or position of a distant object. It was so placed in an optical instrument that the scale marks and the object were seen simultaneously.

Making a graticule involved two main operations. First was the preparation of a blank disc of glass with a highly polished surface free from all imperfections such as pits and scratches. It took some time to convince the firms producing these blanks of the high degree of perfection of surface needed for this work. After many failures both the Australian and British Optical Companies succeeded in making satisfactory discs in large numbers. The second operation was to inscribe the scale marks on the disc. This was done first by covering the disc with a layer of impervious material such as bitumen. With the help of a pantograph, the scale was next drawn by cutting through the bitumen layer with a fine chromium-plated gramophone needle, so exposing the underlying glass for subsequent etching with hydrofluoric acid. On completing the etching, the bitumen layer was removed and the lines filled in by rubbing in printer's ink. This method, and also direct ruling with a diamond tool, was used at the Munitions Supply Laboratories.

When the output of optical instruments increased rapidly, as it did early in 1942, these methods of production were too slow to keep up with demand. It was about this time that Professors Agar,[5] Hartung and Turner,[6] seeking ways in which they could help with war work, visited the Superintendent of the Munitions Supply Laboratories to discuss plans for a graticule annexe at the university. From the discussion it was clear that some of the strain on the Supply Laboratories could be relieved by the establishment of an annexe, and steps were immediately taken to set one up in the laboratories of the Department of Botany.

At first graticules were made by the usual etching process, but while this was going on Hartung set about devising a photographic method of putting scale marks on glass. This he did with considerable success by simplifying the fish glue-lead sulphide process worked out by the British Scientific Research Association. This process had the advantages of speed and accuracy as well as of avoiding etch marks and other damage to the glass surface incurred by the usual method, and these outweighed the disadvantages, such as poor resistance of the graticule to abrasion and its liability to deterioration in the tropics. Graticules intended for use in the tropics were given special proofing treatment which rendered them quite resistant. Official approval of the photographic method was given by the Chief Military Adviser in March 1942. By November 1944 the

[5] W. E. Agar, CBE; FRS, MA, DSc. (Served Highland Light Inf 1914-18.) Prof of Zoology, Univ of Melb, 1920-48. B. Wimbledon, Eng, 27 Apr 1882. Died 14 Jul 1951.

[6] J. S. Turner, MA, PhD, MSc. Prof of Botany and Plant Physiology, Univ of Melb, since 1938. B. Middlesborough, Eng, 9 Sep 1908.

Botany annexe had completed over 20,000 graticules of 60 different types, including those for binoculars being reconditioned in Sydney and Perth, and an order for 188 binocular graticules for the United States Army had been filled.

It must not be thought that the work of the cooperating laboratories was an unbroken record of successes unalloyed with disappointments and unrewarded effort. One difficult instrument whose construction was undertaken by the Department of Natural Philosophy was the Height and Range Finder No. 3, Mark IV. On learning from army authorities that some 65 of these instruments were needed, a team of physicists under the leadership of Associate Professor Martin[7] set out to build a prototype instrument. No drawings of the instrument were available, and only after long hours had been spent on an analysis of an instrument lent by the army were the intricacies of its gears and mechanical parts analysed. When, in August 1941, the first instrument was almost complete, the army cancelled the whole order. Referring to this some time afterwards, the secretary of the panel wrote: "It was extremely disappointing to this laboratory to find that, after such extensive work, all its efforts were of little avail. There was one consolation—the stand of the prototype was used by the army to replace a broken one. It is, however, very difficult to expect continued zealous work by a laboratory when it learns that, after months of work, all effort has been wasted."

On this, the responsible army authorities, who, it should be said, had a very high regard for the work of the Optical Panel, took a different point of view. The course and needs of a war were governed by the action and reaction of two opposing sides, and it was in relation to only one of these that any kind of forecast could be made. War was inherently a wasteful process; every soldier was constantly engaged on difficult, exhausting and often dangerous activities that proved to be fruitless. Probably as much as 90 per cent of a soldier's time was spent in preparation for something that never happened. This being so, scientists had also to be prepared to find some waste in their own efforts, even in the best organised supply systems.

With a background of experience developed slowly over the pre-war years, the Optics Section of the Munitions Supply Laboratories served as the most important centre for the diffusion of optical techniques among contracting firms. A team of experts for computing optical designs was built up and on many occasions these scientists, together with skilled technicians, were lent to contracting firms for months at a time. The section had facilities for making and testing practically every type of optical instrument, and the range of work covered was much greater than in any other Australian establishment. A prototype of every optical instru-

[7] Sir Leslie Martin, CBE; PhD. Assoc Prof of Natural Philosophy, Univ of Melb, 1937-45, Prof of Physics since 1945. Chairman, Defence Research and Develop Policy, since 1948. Of Kew, Vic; b. Melbourne, 21 Dec 1900.

ment made in Australia during the war was thoroughly tested at Maribyrnong.

Before an instrument was passed over to the Services it was thoroughly inspected in a last effort to ensure that it would do what was intended of it. Because optical munitions had never before been made in Australia, many difficulties not met in other fields were experienced in maintaining satisfactory inspection. There were not enough men qualified to do the work until the Munitions Supply Laboratories began training additional army inspectors. Training alone did not solve all the problems of inspection, since doubts sometimes arose over the interpretation of specifications and requirements.

As the basis for his examination of an instrument, an inspector had the specifications which had been drawn up for it, and it was his business to see that the instrument had been constructed in accordance with these specifications. However carefully written, specifications occasionally left something to the judgment of an inspector. For example, a lens was often specified to be made of glass reasonably free from seed (air bubbles) but no explanation was given of what was meant by "reasonably free". Furthermore, some requirements, such as the definition of a telescope, were a matter of subjective judgment. The Optical Panel occasionally intervened when there was evidence that inspection was either not exacting enough or too exacting. On one occasion army inspectors rejected 400 prisms on the ground that they showed tiny scratch marks and chips. The panel set up a special inspection committee to look into this matter. After conducting careful experiments on the performance of the rejected prisms, the committee came to the conclusion that the rejections were unwarranted because when mounted into instruments the prisms gave excellent service. When delivering its judgment the committee observed that "while the makers of optics should endeavour to produce them free from minor defects, no optics should be rejected for a defect which in no way detracted from its performance". Difficulties of this kind were usually obviated by the simple device of supplying the inspectors with approved samples of lenses, prisms or complete instruments so that they might have a basis for comparison.

Although it is at first surprising to find the Commonwealth Solar Observatory entering the field of munitions manufacture, the connection is quite simple: one of the main preoccupations of astronomers was with telescopes, and although they did not usually build their own instruments they necessarily knew a good deal about them and their operation; as already mentioned, nearly all optical munitions contained telescopes.

At the suggestion of the director, Dr Woolley, and with the consent of the Minister for the Interior, the observatory ceased practically all peacetime activities in July 1940 and devoted its resources to making optical munitions. Additional buildings, some of them air-conditioned, were erected and machine tools provided under the Lend-Lease program

were installed.[8] With the machine tools the observatory built its own glass-working machinery. At the peak of its activity some sixty persons were employed, which meant a big expansion of the small community that had made up the pre-war observatory.

All the grinding and polishing machines used were designed in the observatory and made either in its own workshop or in the Department of the Interior workshop in Canberra. Contracts for the production of eleven different instruments were completed. The observatory ranked with the Supply Laboratories and the University of Melbourne as a centre for pioneering optical techniques and for diffusing them to industry. Representatives of most of the firms that became engaged in optical manufacture visited Mount Stromlo at some time.

Much of the work of the Physics Section of the National Standards Laboratory related to the study of the absorption of ultraviolet, infra-red and ordinary light by glasses of all kinds.

It had long been known that observations of an eclipse of the sun made without smoked glass or other suitable moderating glasses could produce serious and often permanent damage to the eyes, known as eclipse blindness. Since eclipses of the sun are fairly rare occurrences, comparatively little attention had been paid to the nature and cause of eclipse blindness, but when anti-aircraft gunners in the brilliant sunshine of the deserts of the Middle East and the tropical regions of the Pacific were forced to look into the sun to observe dive-bombing aircraft, the complaint became of wider interest, this time under the name of anti-aircraft spotters' retinitis. From both these regions came reports of serious injuries to the eyes of anti-aircraft gunners, resulting in permanent blindness.[9] Though these reports were not numerous they were sufficiently serious to cause investigations to be made.

Experiments carried out many years ago[1] on the eyes of rabbits and monkeys led to the belief that damage was caused by overheating of the retina, the region in the back of the eye on which the image is formed. These findings were confirmed at the Kanematsu Institute in Sydney, where an extensive series of experiments was made on rabbits.[2] Briggs and Giovanelli of the National Standards Laboratory then began to study the physical aspects of the problem with the object of finding out what rise in the temperature of the retina could be expected.[3] Calculations based

[8] By the end of the war, Dr Woolley considered, the observatory was equipped as well as, if not better than, the Royal Observatory at Greenwich. This no doubt influenced the Universities of Yale, Columbia and Uppsala when in 1950 they decided to establish an observatory on the slopes of Mount Stromlo. Unfortunately some of this equipment was destroyed in a bush fire during the summer of 1951.

[9] James Flynn (Surg Lt-Cdr), "Photo-retinitis in Anti-aircraft Lookouts". *Medical Journal of Aust* (1942), p. 400.

[1] F. H. Verhoeff and L. Bell, "The Pathological Effects of Radiant Energy on the Eye". *Proceedings American Academy of Arts and Sciences,* Vol. 51 (1916), p. 630.

[2] J. C. Eccles and J. Flynn, "Experimental Photo-retinitis", *Medical Journal of Aust,* Vol. 20 (1944), p. 339.

[3] G. H. Briggs and R. G. Giovanelli, National Standards Laboratory Report PSS. 8 (March 1943).

on mathematical formulae developed by Dr Jaeger[4] and Professor Carslaw,[5] who some years before had made a special study of the conduction of heat, led them to the following conclusions: that the visible and infra-red light from the sun were about equally responsible for the temperature rise of the retina; and that the rate of the temperature rise was very rapid—practically the whole rise (95 per cent of it) occurring within half a second.

Having established these facts they set about devising suitable goggles using tinted, infra-red-absorbing glass. The "lenses" of the goggles were flat pieces of glass of the kind used in welders' goggles. In this there was of course nothing new. The novelty they introduced was to place in the centre of each lens two small thick discs of very dark welders' glass fused on to the main disc by an ingenious process developed and patented by the Council for Scientific and Industrial Research.[6] These discs, of just the right size to block out the sun, reduced the light reaching the eye to about one-millionth of that which would otherwise reach it, so that one could look through the disc directly at the sun and see it at the same brightness as the rest of the sky. Under these conditions it was quite easy to see a plane silhouetted against the sun. These goggles, when tested in experiments carried out in conjunction with anti-aircraft defences, Sydney, in which a dive bomber attacked from the sun, were found to improve the efficiency of members of the gun crew. The goggles were adopted first by the navy and later by the other two Services.

Physical problems relating to "dark adaptation" by gunners and pilots were also studied in the Physics Section.[7] The problems encountered were of two main kinds. First there was the problem of how to reduce eye fatigue of pilots flying at night and forced to read the blue self-luminous dials of the instruments on their control panels. A group of Catalina flying-boats based on Cairns used to make regular flights known as the "milk run" to the north over Rabaul and its surrounding territory; the flights lasted twenty-four hours. Reports came in of severe fatigue experienced during these long flights, some of it doubtless due to eye strain, and it was clear that anything at all that could be done to reduce the strain would be well worth while. A second, closely related problem, was to accustom the eyes rapidly to seeing in the dark. Anyone who has gone from sunlight into a darkened room will recall the difficulty experienced at first in finding the way round. After twenty minutes or so the eyes become dark-adapted and it is then much easier to see in dim light. In the operations of war there were a number of situations in which it was necessary for the eyes to adjust themselves rapidly to a dim light: a night pilot had to look from the light of his cockpit to the outside darkness and do

[4] J. C. Jaeger, MA, DSc. Lecturer in Mathematics, Univ of Tasmania; Research Officer Radiophysics Laboratory CSIR; Prof of Geophysics, Aust National Univ, since 1952. Of Hobart; b. Sydney, 30 Jul 1907.

[5] H. S. Carslaw, DSc. Prof of Mathematics, Univ of Sydney, 1903-35. B. Helensburgh, Scotland, 12 Feb 1870. Died 11 Nov 1954.

[6] Australian Patent Application No. 11216/43.

[7] This work was done by a team under the leadership of Dr G. H. Briggs, the Officer-in-Charge of the section, and included R. G. Giovanelli, E. H. Mercer and FO C. J. Mathieson.

his best to spot the enemy; men on a ship in their lighted quarters, due to go on duty on the bridge or called suddenly to action stations in the dark, had an advantage if they were immediately able to see in the dark to their maximum ability. In both cases it would obviously be impossible, or very inconvenient, to wait twenty minutes for the eyes to adapt themselves.

Early in 1940 Dr V. D. Solandt and Dr C. H. Best (one of the co-discoverers of insulin) found that a person's eyes could be adapted to seeing in the dark by his remaining in a room illuminated quite brightly with red light for about thirty minutes.[8] The first application of this fact seems to have been made in Canada in December 1940 when night trials were carried out in R.C.A.F. aircraft under the direction of Wing-Commander T. R. Loudon. This led to the practice of night-fighter pilots' wearing red goggles while they were standing by for emergencies.

The explanation of the usefulness of red light for this purpose rests on the fact that the retina of the human eye contains two kinds of light-sensitive elements: the cones, which operate in bright light and are responsible for colour vision, and the rods, which provide the special sensitive elements for seeing in dim light where their excitation yields only sensations of neutral grey. The rods contain a pigment known as visual purple, and it is the absorption of weak light by this pigment that makes the rods light-sensitive. In bright white light, however, visual purple is bleached, and the rods cannot function. By resting in the dark visual purple is regenerated in the rods and in this way ability to see in a dim light may be restored. Although bright white light bleaches visual purple, red light of the right wavelength has little effect on it. Hence, by wearing red goggles in a room illuminated with ordinary white light or daylight, a person can become dark adapted. The glass of the goggles must be of such a shade of red that it will admit light without affecting the rods. The Physics Section drew up the specifications for such a glass, which was subsequently made by Australian Window Glass Pty Ltd.

The problem of how best to illuminate the control panels in the cockpits of night-flying aircraft was solved by using the same kind of light as was needed for dark adaptation. Early in the war aircraft instrument dials were marked with a self-luminous paint excited to a blue phosphorescence by the addition of traces of radium or mesothorium. This faint blue light was the worst kind of light under the circumstances, because with it sharp vision was impossible. To understand the usefulness of red light in reducing eye fatigue in night pilots it is necessary to consider in a little more detail the structure of the retina, the light-sensitive portion of the eye.

Detailed study of retina shows that clusters of rods (the dim-light, sensitive elements) are connected to the brain by one nerve fibre; cones near the centre of the retina are connected individually to the brain. Rods therefore transmit a rather fuzzy stimulus to the brain and sharpness of

[8] W. Eggleston, *Scientists at War* (1950), p. 247.

vision or detailed vision is not possible in a dim light. Visual acuteness is achieved in bright light by means of the small central area of the retina, known as the fovea. The fovea includes what is called the fixation point of the eye. To look directly at something is to turn one's eyes so that its image falls on the fovea, a small area no bigger than a pin's head in which only cones are to be found. Rods and cones are sensitive in varying degree to light of all colours, but the cones are more sensitive to red than the rods.[9] Light from blue self-luminous radium paints is insufficiently intense to excite the cones appreciably, and although it does excite the peripheral rods distinct and sharp vision is unattainable because of the way the rods are linked up to the brain. On the other hand, a sufficiently bright red light stimulates the cones and when it is focused on the fovea clear and sharp images are formed. At the same time the red light has relatively little effect on the rods and therefore does not hinder dark adaptation of the eye.

These, then, were the reasons why cockpits of Beaufort bombers and Catalina flying-boats were adapted to the red flood-lighting system. Special cockpit lamps were designed and photometers made for measuring the intensity of the red illumination. Because it was necessary to ensure that pilots would be able to adjust the brightness levels sufficiently to cope with a wide range of light outside the aircraft, which of course varied according as it was dawn, dusk, full moonlight, starlight or a very dark night, extensive studies were also made of factors affecting dark adaptation of the eye under all conditions.

Crews of the Catalina flying-boats were enthusiastic in their praise of the improvements brought about by the changeover to the system of red flood-lighting. Another solution to the same problem, successfully developed overseas, was to use self-luminous paint so compounded as to luminesce an orange-red colour. Instrument dials marked with this luminous paint were reasonably easy to read and the light had the virtue of being independent of electric batteries.

The most creditable achievement of the University of Sydney in the field of optical munitions was the production of the ring-sight telescope, an instrument given high priority in the list of army requirements. Its construction was planned as an insurance against the possible failure of the program of work on electrical predictors undertaken independently of the Optical Panel. The contract was given to the University of Sydney because no commercial firm would undertake it; the work was very intricate, and the number required—85—made mass production impracticable. This was the only instance of a university becoming a major contractor for the manufacture of a large and complicated instrument.

The ring-sight telescope was an accessory of anti-aircraft guns and was in the nature of an optical predictor, an instrument which when trained on a moving target indicated (at least in theory) to the gun crew the correct

[9] The spectral response curves of the two are well known: the maxium sensitivity of cones occurs at a wavelength of 5550A and that of the rods at 5050A.

point of aim and fuse setting to cause a shell to explode on the target. It was described by Professor Vonwiller as being mechanically and optically one of the most complicated of military instruments, including twenty-eight lenses and prisms and several intricate moving parts. Since none of the experts at Maribyrnong or at any of the other cooperating laboratories had had any experience with this kind of instrument, the university was thrown on its own resources.

It experienced all the inevitable setbacks of wartime: materials that were slow to arrive, and sub-contractors who failed to complete their tasks on time because of shortage of machine tools, and for other reasons. In an effort to speed up work at the university, working hours were increased to sixty-two a week, in some instances with disastrous results; several members of the staff, who were carrying on their normal teaching work at the same time, broke down in health and there was a general loss of efficiency. The team at length triumphed over all its difficulties and instruments were produced at a rate well ahead of the guns with which they were to be used. Then came a disappointment similar to that experienced by the workers at Melbourne University. When scarcely more than half the instruments had been completed word came through that no more were required. By 1944 the Japanese had been defeated in the air, and few anti-aircraft guns were needed. Some, at least, of the instruments were used and to good purpose. Reports came back from New Guinea that the ring-sight telescope was, because of its lightness and compactness, successfully used in the jungle where it would have been quite impracticable to use heavy electrical predictors weighing some tons.

Among other tasks successfully accomplished at the University of Sydney, the most notable was the reconditioning of about 10,000 binoculars that had been called in from the public. The binoculars were fitted with graticules and the two telescopes of which they are composed were accurately aligned. This adjustment had to be made in the majority of the instruments. Unless the two parts were strictly parallel, eyestrain was likely to result from their continuous use. Mr G. A. Harle devised a special arrangement for rapidly making the axes of binocular telescopes parallel, but even with this aid many people had to be employed on the work. At the height of its activities the Physics Department employed about 140 workers, mainly women and girls, most of whom were engaged in reconditioning binoculars.

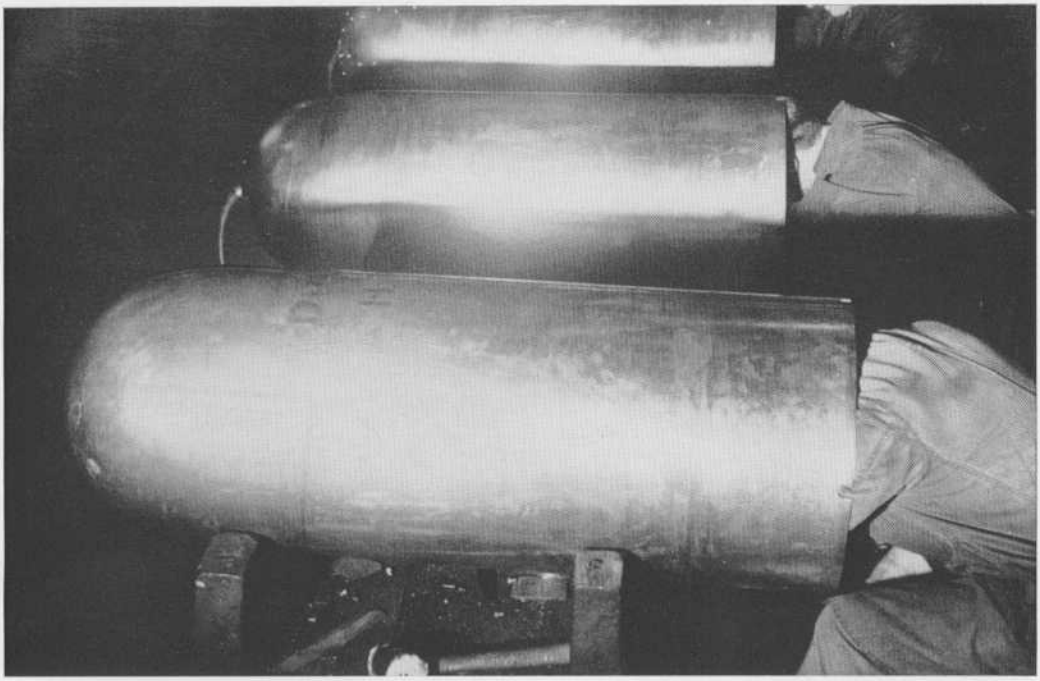
The University of Sydney was the main centre for the development of a process known as blooming, a method of treating glass surfaces to increase the amount of light passing through the glass by reducing losses by reflection. The importance of the process was that it could be used to increase the performance of an optical instrument in poor light. Telescopes had occasionally to be used in the early dawn, a period of great danger on land or sea because of enemy approaches during the hours of darkness. An aerial photograph might have to be taken under similar adverse conditions. It was therefore important to ensure that the telescope or camera transmitted as nearly as possible all the light reaching it.

As long ago as 1892, Mr H. D. Taylor, an English lens expert, discovered that a photographic lens which had become accidentally tarnished and apparently spoiled gave a much better performance than an untarnished lens in that it transmitted more light. The cause of this was not understood until 1935, when J. H. Strong and other American workers correctly attributed it to a thin film of transparent material on the glass surface. Optical theory showed that if a glass surface was coated with a transparent film of a thickness equal to one quarter of the wavelength of light, and if the film's index of refraction was equal to the square root of the index of refraction of the glass, all the light falling on the glass passed through it and none was lost by reflection. For several reasons these conditions could not be fully satisfied. The required film thickness varied with the wavelength of light used; white light covered quite a wide range of wavelengths. The refractive index of all known materials suitable for forming films was in every instance greater than the desirable value, but with a fairly close approach to this value reflection could be considerably reduced in the spectral region to which the eye was most sensitive (the green-yellow region).

The process of depositing a hard, transparent and adherent thin film on glass was quite a straightforward one, but it had to be carried out in a very high vacuum. The material from which the film was formed depended on the nature of the underlying glass. Magnesium fluoride, one of the substances extensively used for this purpose, required a high temperature to cause it to evaporate. It was therefore placed in a small electrically-heated molybdenum boat above which, and at some distance, was suspended the glass object whose surface was to be coated. The whole arrangement was covered with a large glass bell jar from which air was then completely withdrawn by means of powerful high-vacuum pumps. Control of the thickness of the film deposited was achieved by noting the time for which it was allowed to grow. Only very thin films of the order of a few hundred thousandths of an inch were required. A rough idea of their thickness could be gained by observing the interference colours of the films when illuminated with white light.

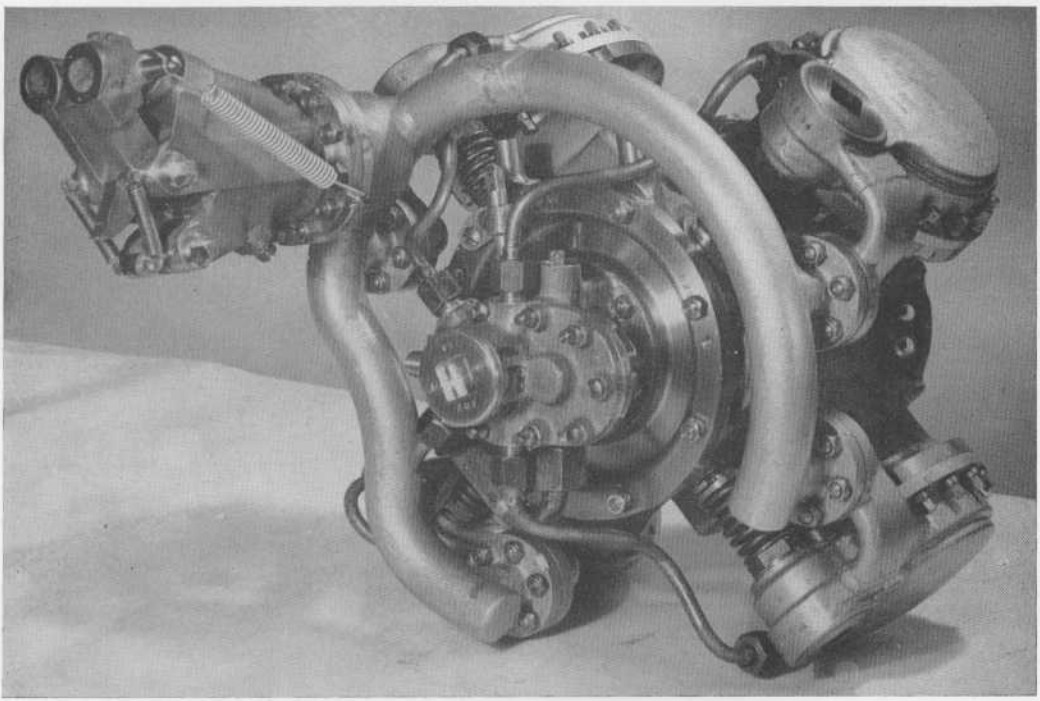
With an untreated lens the loss of light by reflection was between 4 and 6 per cent, depending on the kind of glass. In a complex optical instrument this loss occurred at each glass surface, so that the ring-sight telescope with its twenty-two glass surfaces transmitted only about one quarter of the light reaching the objective of the instrument. Dr Bannon,[1] who developed the blooming process at Sydney, was able at an early stage of his work to increase the light transmitted by the ring-sight telescope from 27 to 47 per cent, and that of binoculars from 50 to 75 per cent. Later work gave even better results but came too late to have any real usefulness during the war. The results afford, however, some idea of the proficiency with which this technique was developed. The laboratories at Hobart and Maribyrnong took up the process later, and in the immediate

[1] J. Bannon, DSc. Research officer Radio Research Board 1938-42; C'wealth Research Fellow 1942-45; Lecturer in Physics, Univ of Sydney, since 1946. Of Sydney; b. Ireland, 16 Sep 1900.

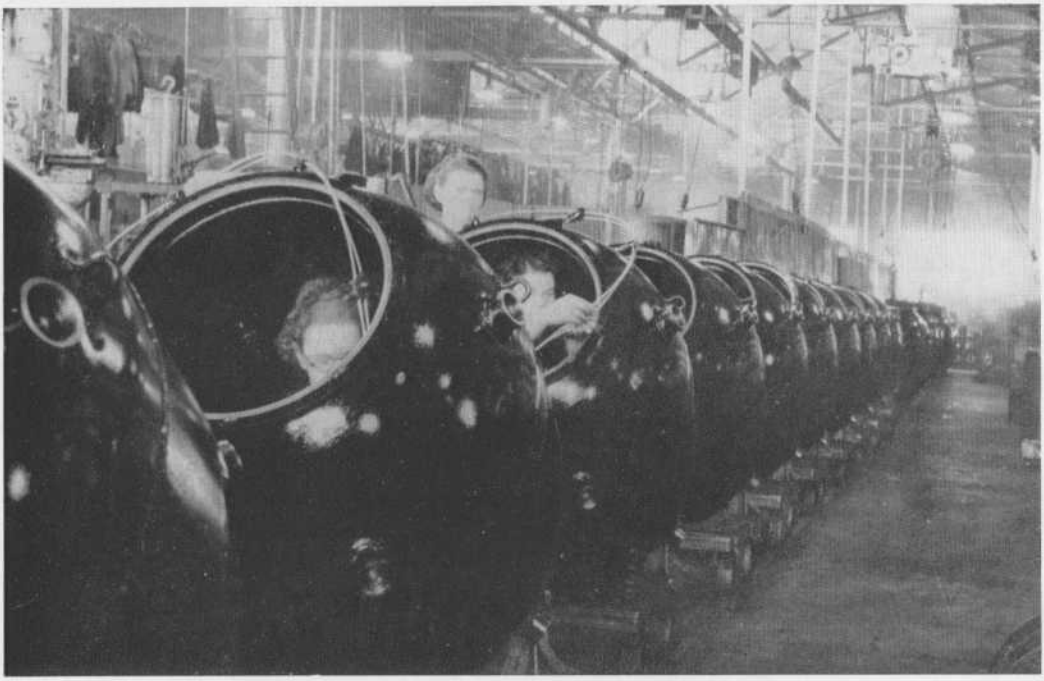


(Dept of Defence Production)

Skill in difficult positions was demanded of the men who made torpedoes. Here the finishing touches are put on the insides of torpedo warheads.

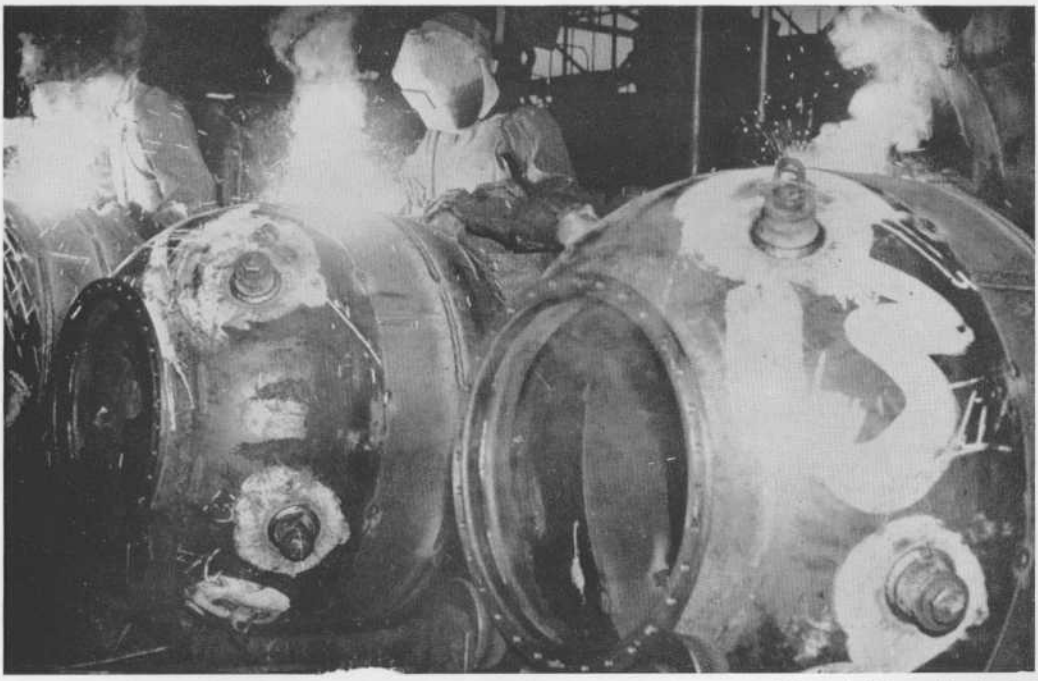


Torpedo engine made by General Motors-Holden's. 225 h.p., weight 125 pounds; fitted into a chamber about 17 inches in diameter.



(Dept of Defence Production)

Installing main wiring ring in mine shell.



(Dept of Defence Production)

Welding horn bosses, and welding hemispheres to mine belt.

post-war years much use was made of it, particularly at Hobart, in treating lenses of aerial and cinematograph cameras.

The University of Sydney served as a centre for the dissemination of a knowledge of the principles of optical design, and special lecture courses on geometrical optics were given by Esserman, Vonwiller and Harle.

In Tasmania, Professor McAulay[2] took up the work on optical munitions with enthusiasm and in a very short time spherical and flat surfaces were being worked in the laboratory by members of his staff and senior students. In this development he was helped by Mr Waterworth,[3] a man of considerable ingenuity and mechanical skill, and Mr Cruickshank,[4] whose work in optics led to useful original contributions to that subject.

At one of the early meetings of the Optical Panel, the question of making glass prisms came up for discussion. It had been realised earlier that making prisms would present difficulties, and at first it was hoped to avoid them by using aluminised mirrors as substitutes. McAulay's group however accepted the challenge and began work immediately. The difficulties inherent in making prisms may be gathered from the fact that the surfaces of prisms must be optically flat—that is, level to within about one-millionth part of an inch—and the angles between the surfaces must, in the most exacting instance, be accurate to within a few seconds of arc. To achieve this degree of accuracy Waterworth designed a number of ingenious jigs, which located prism blanks so accurately that relatively little skill was demanded of the operator. Waterworth's method of doing this was novel and did much to make possible Hobart's extraordinary output of prisms. All the machinery used in the specially constructed Optical Annexe built for the Commonwealth Government in the grounds of the university was designed and made in Hobart.

It was not long before they were able to produce satisfactory prisms of all kinds: prisms for range finders, periscopes, aerial cameras and many other instruments. The staff of the annexe grew from 6 to 200 within a year, the new recruits being mostly untrained girls. In its four years of operation the annexe turned out some 14,000 prisms, valued at about £250,000. The high optical standard of this work was attested by the Physics Department of the University of Melbourne, where exacting interferometric tests capable of revealing the most minute optical imperfections were made on the prisms.

During a visit to the United States in 1942 Hartnett, finding that country very short of prisms, arranged for a shipment of about 7,000 roof prisms made mainly in Hobart to be sent to the Frankford Arsenal. Notwithstanding the fact that the standards of inspection there were most rigorous, the prisms were favourably received.

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[2] A. L. McAulay, MA, BSc, PhD. Prof of Physics, Univ of Tasmania, since 1927. B. Hobart, 15 Nov 1895.

[3] E. N. Waterworth. Instrument maker; of Hobart; b. Hobart, 15 May 1905.

[4] F. D. Cruickshank, DSc. Assoc Prof of Physics, Univ of Tasmania, since 1949. B. Hobart, 3 Jul 1908.

One of the outstanding achievements of the Hobart Annexe was the designing and making of aircraft camera lenses. In face of great difficulties, such as inadequate testing equipment, glass and machine tools, and the inability to obtain adequate and continuous funds for development work, the annexe succeeded in making more than 100 lenses for the R.A.A.F. At no time was optical glass of the required type available for the manufacture of aircraft lenses of standard designs; each type of lens had to be redesigned to permit the use of those glasses that were at hand. Such difficulties were rapidly overcome. For example, in the short time of six weeks a lens with a focal length of 36 inches was designed and made, and by means of aerial photographs was shown to compare very favourably with a British lens of the same focal length. It was later sent to the British Admiralty for report, and found to be only slightly inferior to later British models. While developing methods for making camera lenses at Hobart, McAulay and Cruickshank worked out important and entirely new methods for calculating lens shapes, details of which were not published until after the war. Their methods of computing the effect of small changes in the dimensions of a lens on the formation of an optical image, were taken up by oversea optical firms.

In every optical instrument for measuring or fixing direction with regard to the horizontal—in gunsights of all kinds, height, range and position finders, and director telescopes, to name only a few—a spirit level or bubble was needed to define the horizontal plane or vertical direction. Bubbles of this kind had not previously been made in Australia, and at the beginning of the optical munitions program an urgent need for them arose. At the instigation of the Directorate of Ordnance Production, Kerr Grant, Professor of Physics in the University of Adelaide, undertook their production. A satisfactory technique for making bubbles was devised by Mr H. R. Oliphant, a technician in the Physics Department. It was soon shown that there were no technical difficulties in the way of manufacturing spirit levels in Australia, and in a short time details of the technique were handed over to Claude Neon Lights Ltd and the Precision Glass Instrument Company, both of Victoria. Before June 1941 some 4,000 of every type needed for optical munitions had been produced. After that, bubbles were made at the rate of 10,000 a year by amazingly simple methods. Some of the bubbles were extremely sensitive, being capable of detecting a slope of one inch in three miles and a half.[5]

In spite of its great distance from the industrial centres of the eastern States and the difficulties of communication, the Physics Department of the University of Western Australia, under Professor Ross, did its share of work in optical munitions. It reconditioned and tropic-proofed a large number of binoculars, assembled and repaired many instruments, and made graticules and test plates.

[5] Kerr Grant, "The Making of 'Bubbles' for Spirit Levels". *Australian Journal of Science*, Vol. 3 (1941), p. 147.

Except for work on tropic proofing, the greater part of the optical munitions program was completed by the end of 1943. Many of the later meetings of the panel were therefore devoted to discussions on the fate of the optical industry after the war. The panel was unanimous on the need for maintaining training and research in both pure and applied optics, and it set out in detail schemes for the training of physicists in what it regarded as the most appropriate universities for this work, namely Tasmania, Melbourne and Sydney.

On 6th December 1945, when it seemed to have fulfilled its purpose and was no longer able to find useful activity, the panel was dissolved. Whatever the shortcomings of its constitution—the panel had its critics—it had done a fine piece of work and had gained the confidence of the army as few other scientific bodies had done. All the instruments the three Services had asked for had been produced. The panel was fortunate in having as its chairman (from its inception to March 1944) Professor Laby, one of Australia's outstanding physicists. Throughout his scientific career Laby proved himself an experimenter of the first order. His work on the precise determination of the mechanical equivalent of heat became a classic in this branch of physics. He had an abiding passion for accurate measurement, which further displayed itself in his work on the charge of an electron. One of his colleagues said of him: "No physicist had a greater respect for precision, and his genius lay in a capacity to design an experiment to achieve it."

Towards the end of 1943 the Commonwealth Government set up the Secondary Industries Commission for the purpose of investigating methods of ensuring a smooth transition of war industries to a peacetime basis.[6] To assist the commission a number of advisory panels were formed. Among them was the Optical Industry Advisory Panel, the members of which were recruited from the Scientific Instruments and Optical Panel. The terms of reference of the Advisory Panel were to consider:

(*a*) the ability of the optical industry from the standpoint of technical and scientific resources to undertake commercial production;
(*b*) the possibility of the industry operating as a commercial undertaking;
(*c*) if (*b*) were not possible, whether the industry was of sufficient national importance to justify special action by the Government to retain it after the war;
(*d*) the future of skilled labour and technical and scientific resources developed in optical munitions production during the war.

The panel went into these questions at great length and made a number of recommendations to the Secondary Industries Commission. For example, it strongly recommended that the Commonwealth Government should make available a sum of money for experimental work on optical glass to be made in small platinum pots. It also recommended that every effort

[6] The commission held its first meeting on 15 Nov 1943. Its members were: J. K. Jensen, Secretary, Dept of Munitions (Chairman); D. J. Nolan, Chairman, Standing Ctee of Allied Supply Council; F. T. Merrett, Director of Small Craft Construction, Dept of Munitions; W. D. Scott, Finance Member, Board of Area Management; S. F. Cochran, Chairman, State Electricity Commission of Q'land.

should be made to put the optical industry on a commercial basis after the war. The Secondary Industries Commission, convinced that the economic future of the optical industry was too insecure and that the possible market for each of many types of instrument was far too small, decided that it could not recommend to the Government any of the proposals made by the Optical Industry Advisory Panel, not even the one dealing with provision of money to support small-scale experimental work on optical glass. This decision put an end, for some years at least, to any hope that a rationalised commercial optical industry might be developed with the help of the Commonwealth Government. All that remained of the wartime optical industry was the annexe at Hobart, which the Commonwealth Government sold to Waterworth. Here the successful production of film-strip projectors, lenses and prisms was in 1955 still being carried on though with increasing difficulty because of rising costs.[7] Up to this time nothing had been done either by government or private research laboratories to revive work on optical glass, even on a small scale, by using platinum pots as had been recommended by the Optical Advisory Panel. At this period important advances were being made in optical glass overseas. New and extraordinary types of high refractive index glass for aerial camera lenses were being developed. Ironically enough, one of the most notable developments in 1955 was the manufacture of glass on a commercial scale in large platinum pots, thereby greatly increasing the yield of glass from below 20 to over 70 per cent.

The problem of keeping up to date in the optical industry was of course not peculiar to Australia. It arose even in the United States, the most highly industrialised of nations. There as elsewhere the peacetime annual requirements of precision optical instruments were small compared with wartime demands, and much thought was given to the problem of keeping abreast of scientific progress made in the laboratory. The advice given by Condon applied equally well to Australia:

> If we are to be again prepared for future emergencies, a program of research and experimentation must be maintained. Stockpiling of optical glasses is not a solution, for stockpiling tends to maintain the *status quo,* saddling the military services with obsolete instruments and making the introduction of better glasses and instruments difficult. As a general rule, with valid exceptions only in the case of basic raw materials, stockpiling is futile and tends to hinder progress. The only sensible solution is a progressive research program involving the new type of optical glass, analysis of the physics and chemistry of optical glasses and development of new and more efficient methods of processing optical glass.[8]

Failure to follow up in any way the wartime successes with optical glass in Australia was the darker side of the picture; on the brighter side was the work of the university departments of physics (especially that of Tasmania) and government laboratories. Often considerably helped

[7] A scheme for making microscopes for students was completed, but not by private industry. As originally planned, the lenses were made by the Munitions Supply Laboratories, and owing to the failure of a private firm to complete the order for stands the Munitions Supply Laboratories finally made the whole instrument. In all some 500 microscopes were supplied to the Universities Commission.

[8] E. U. Condon, "Science and the National Welfare", *Science,* Vol. 107 (1948), p. 5.

in the immediate post-war years by equipment and materials acquired through the Disposals Commission, these laboratories continued to prosecute research on optics and optical instruments so that at least the scientific basis for an emergency optical industry was encouraged and developed.

CHAPTER 13

TORPEDOES AND MINES

THE decision to manufacture torpedoes in Australia, taken at a meeting of the War Cabinet on 22nd December 1941, committed the country's precision engineering to a most difficult undertaking; by reason of the position occupied by torpedoes among modern armaments, the undertaking was one of great potential importance.

With sea power as the corner-stone of Britain's dominant strength among world powers in the nineteenth century it is not surprising that the development of the torpedo was essentially a British achievement, though it was not in the first instance a British invention.[1] Britain's early lead in the adoption of the torpedo owed much to the enthusiasm of Commander (later Admiral Lord) Fisher, but other great powers were not long in entering the field. The tremendous possibilities of the weapon were first apparent during the war of 1914-18 when Germany, by means of the U-boat and the torpedo, inflicted such heavy losses on merchant shipping that she very nearly brought Great Britain to her knees. During the two decades that followed the first world war the torpedo acquired even greater destructive potentialities by the development of methods for dropping it from aircraft, and no great insight was required to predict the part the torpedo would play in a future war.[2]

The manufacture of torpedoes in Britain was carried out principally by a private firm, the Whitehead Torpedo Company, which manufactured for all comers, and by the Admiralty at Greenock, Scotland. In July 1941 the Admiralty, concerned at the possibility that Britain's production of torpedoes might be hindered if not prevented altogether by bombing or invasion, began to investigate means of providing alternative centres for such an emergency. Manufacture in Britain had been decentralised as far as practicable but nothing had been done towards establishing centres outside Britain.

In a message to the Australian Naval Board on 15th July 1941 the Admiralty stated: "It would be a considerable advantage if torpedo manu-

[1] It is generally agreed that the torpedo developed from a device conceived by Capt Giovanni Luppis of the Austrian Navy. In 1864 Luppis approached Sir Robert Whitehead, English manager of an engine factory at Fiume, with a scheme for a self-propelled boat steered by a long yoke line from the shore and carrying an explosive charge in the bows. Whitehead made a model embodying these proposals but soon abandoned the device as impracticable. The germ of the idea had, however, been successfully sown and Whitehead, after two years' experimenting on depth and steering controls, succeeded in building a device closely resembling the torpedo used in the war of 1939-45. It was a fishlike object 14 inches in diameter, weighing about 300 pounds and driven by compressed air at a speed of 6 knots for a distance of about 100 feet. Although it was a crude affair its potentialities were recognised by a group of British navy officers, who persuaded Whitehead to bring his invention to England.

Acting on the advice of the Admiralty "that any maritime nation failing to provide itself with submarine locomotive torpedoes would be neglecting a great source of power for offence and defence", the British Government bought Whitehead's invention for £15,000.

Some 10 years later an Australian, Louis Brennan, worked on the idea of a torpedo seriously enough to persuade the Government of the Colony of Victoria to give him a grant of £700. His invention was eventually bought by the British Government.

[2] The first tests on launching torpedoes from an aircraft are said to have been made in Italy in 1911. The Royal Navy ordered its first special plane for torpedo carrying in 1913, but the big developments occurred in the inter-war years.

facture could be started in Australia which could then serve as a source of supply for the Middle and Far East." As soon as the Department of Munitions was able to assure it that Australia's engineering resources were likely to be equal to the task, the Defence Committee recommended that the local manufacture of torpedoes suitable for launching from aircraft should be undertaken.

On the advice of the Admiralty, the War Cabinet approved the Defence Committee's recommendation and allotted the sum of £1,000,000 for setting up the necessary plant. Production was planned for a weekly output of ten 18-inch Mark XV torpedoes, some of which were intended for use by the R.A.A.F., and it was estimated that it would be about eighteen months before production could begin.[3] The possibility of invasion by the Japanese gave a new sense of urgency to the project. It was realised that little could be done to prevent the Japanese from landing somewhere along the extensive Australian coastline, but that if such a landing occurred one of the most effective forms of retaliation would be to cut off supplies from the invading force. Wherever the Japanese might establish themselves on the mainland, supplies, food and arms carried by fleets of transport ships would be essential. Consequently in plans for the defence of Australia the building of Beaufort torpedo-bombers and of torpedoes for launching from them was given the highest priority.

Among important factors that govern the successful use of war weapons, two stand out: firstly, they must be capable of being safely handled by the fighting forces; secondly, they must be as nearly perfectly reliable in their expected performance as it is humanly possible to make them. These conditions applied with particular force to torpedoes. In perhaps no other weapon was reliability so important. When approaching its target, an aircraft, ship or submarine might have to run considerable risks before the torpedo could be launched. Only if the men had complete faith in the efficiency of their weapons could they be expected to press home such an attack with confidence and to take the great risks involved in so doing. The high order of engineering skill necessary to achieve this reliability meant that the decision to undertake the local manufacture of torpedoes was a very onerous one.

In the period between the wars the Royal Australian Navy adopted a policy of transferring officers to the Royal Navy either on loan or exchange, so that they might become familiar with Royal Navy procedure or take technical courses in the United Kingdom. Several engineer officers were given courses in armament production which included visits of several months to various torpedo establishments. It was fortunate that the Armament Assistant at Garden Island, Commander Urquhart, had just returned to Australia after completing such a course at the Torpedo Factory, Greenock, and was therefore available on the spot to prepare the preliminary layout and design of a torpedo factory. In this work he was

[3] The original order was 500 for the Admiralty, 280 for the RAAF, the latter to have priority.

assisted by the foreman of the Torpedo Depot at Garden Island, Mr Florence,[4] who had been sent to Britain in 1938 to study the manufacture, ranging and maintenance of torpedoes in the Royal Navy establishments. It was possible, under these conditions, to proceed with the plans and construction of a factory before the arrival of the Superintendent designate, Engineer Captain Mears.[5]

Mears, an officer on the sea-going list who had a long and wide range of experience in naval engineering, was then on the staff of the Australian High Commissioner in London, where his chief duty was to act as a technical liaison officer between the Admiralty and the Australian Naval Board. In this capacity he had been closely associated with overtures to the Australian Government on the subject of making torpedoes. This, with his experience at the Torpedo Depot at Garden Island, singled him out as an Australian naval engineer equipped to lead the new project. Once the decision to make torpedoes in Australia had been taken, Mears was released from his duties with the High Commissioner in order that he might visit the Admiralty establishments at Greenock, Weymouth and Bournemouth to study the latest methods and operational sequences used in manufacturing and assembling torpedoes. He also studied the problems likely to be encountered in setting up a range for testing torpedoes. On his way back to Australia he took the opportunity of visiting American establishments making the type of torpedo that was to be made in Australia. From them he obtained further insight into manufacturing and safety measures.

The site chosen for the factory was that of the North Sydney Gasworks, and as a result of quick and effective action by the Business Board immediate possession was gained late in 1941. The original plan was to economise by adapting the existing buildings, which were in some respects suitable, but when after several months work had not even begun, the navy sought the aid of Mr Essington Lewis. Lewis decided that to keep pace with the program agreed upon it was necessary to demolish the existing building and erect an entirely new factory. The next day, a Friday, he called a meeting at his office in Melbourne which was attended by all concerned, including representatives of the architects and the contractor from Sydney.[6] A contract was placed that night and the contractor began to clear the site on the following Monday morning. This was a good example of what could be done when it was possible to make a clean cut through red tape. By February 1943 the buildings, known as the Royal Australian Naval Torpedo Factory, were completed, in remarkably short time. The factory was well designed and splendidly equipped; so completely did its structure harmonise with its surroundings that despite the

[4] E. M. Florence. Served with RAN and at RAN Torpedo Depot, Garden Island, 1929-42; Superintendent Foreman, RAN Torpedo Factory, 1942-46. B. Lossiemouth, Scotland, 19 Sep 1902.

[5] Engr Capt A. C. W. Mears, CBE; RAN. Naval Engineer Officer on staff of High Commissioner for Aust, London, 1938-42; Superintendent RAN Torpedo Factory 1942-46. Of Kew, Vic; b. Serviceton, SA, 7 Jun 1890.

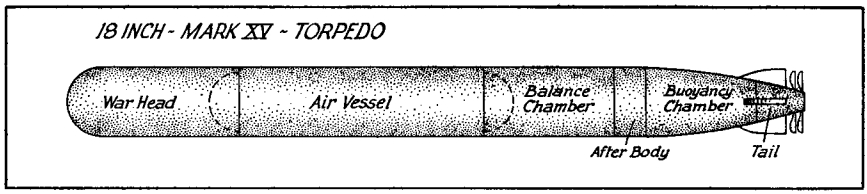
[6] The establishment was designed by Messrs Stephenson and Turner, with Concrete Constructions Pty Ltd as contractors; construction was begun in March 1942.

fact that it covered over 100,000 square feet, it was by no means a conspicuous landmark.

The basic problems associated with the manufacture of torpedoes were similar to those met in establishing other forms of new production. Drawings and specifications, however complete, merely stated the requirements to be met; how they were met depended on the nature of the work force and the plant and manufacturing equipment available. At Garden Island there was a staff of men experienced in the overhaul and modification of torpedoes, and also equipment which could be used to form the nucleus of a centre for the final assembly of torpedoes. This was in fact to be the main function of the new factory. On the other hand it was recognised that although the manufacture of components for torpedoes employed processes already in use in Australia, much time would be saved if instead of trying to evolve a satisfactory technique by trial and error, specialists were brought in from Britain. This was done. Before his return Mears arranged for three men of the Torpedo Factory at Greenock, each specialising in a different phase of manufacture, to come to Australia. However there were many local problems of manufacture which did not need the help of these specialists, and to investigate these the Directorate of Ordnance Production formed a team of production engineers.

The vital and exacting task of inspection, which following the general practice was kept quite distinct administratively from manufacture, was performed by the Naval Ordnance Inspection Board under Commanders Nurse and Godsell.[7] They were later joined by Mr P. Chard from the Whitehead Torpedo Factory in England, and by Commander Schunck[8] who was lent by the Admiralty to assist in building up an inspection staff.

As conceived by the navy the whole project was the responsibility of the Director of Ordnance, Torpedoes and Mines, Captain Spooner,[9] but was carried out to navy requirements by the Directorate of Ordnance Production under the guidance of Mr Hartnett and Mr Daley, with Mr Poulton[1] as Project Manager.



So that the reader may more easily follow the general account of the manufacturing processes, a brief description is given of the torpedo. From

[7] Engr Capt T. A. Godsell, RAN. Assistant Inspector of Naval Ordnance 1936, Deputy Inspector 1942, Chief Inspector since 1948. Of Melbourne; b. Melbourne, 6 Jun 1903.

[8] Capt F. Schunck, RN. Inspecting Torpedo Officer, RN Torpedo Factory, Greenock, to 1942; on loan to RAN 1942-46. Of Dorset, Eng; b. Buxton, Derbyshire, Eng, 8 Mar 1899.

[9] Capt L. A. W. Spooner, OBE; RN. Served RN 1900-31, RAN 1931-46. Of Beaumaris, Vic; b. Reading, Eng, 18 Apr 1885.

[1] J. H. Poulton. Manager Stirling Henry Ltd to 1942; Project Manager Torpedoes; later Assistant Controller, Mechanical and Electrical Division O.P.D., 1942-45. Of Sydney; b. Melbourne, 17 Jul 1905.

the accompanying diagram it will be seen that the torpedo was divided into five main compartments:

(*a*) the war head, containing the explosive charge and the means of detonating it;
(*b*) the largest compartment, the air vessel, which contained air at a pressure of about 3,000 pounds per square inch;
(*c*) the balance chamber, containing the mechanism to regulate the depth at which the torpedo ran, the fuel and lubricating oil bottles, and the engine;
(*d*) the afterbody, which provided buoyancy and contained the gyroscope which controlled the steering gear of the torpedo;
(*e*) the tail piece, containing the tail gearing, contra-rotating propellers, horizontal rudders to keep the torpedo at its set depth and vertical rudders to steer the torpedo.

The torpedo was in effect a miniature robot submarine whose performance depended upon the perfection of its manufacture, for once it was fired it was completely outside human control.

The type of torpedo to be made in Australia, known as the 18-inch Mark XV, was designed specially for launching from aircraft, but it could also be launched from ships. Mark XV was developed from earlier ship types by strengthening its structure so that it could be safely dropped from greater heights and at greater speeds. Its manufacture provided an example of successful cooperation between government and private industry. The torpedo lent itself admirably to manufacture in major sections or assemblies. Only in a few instances were single components let out to contractors. The final assembly of components and major sections was carried out at the Torpedo Factory at North Sydney.

The destructive end of a torpedo, the war head, was a hollow, dome-shaped metal structure which carried an explosive charge consisting of about 500 pounds of Torpex and the mechanism for setting the explosion at the right moment. The explosion occured in two stages, the main one, in the Torpex, being initiated by the detonation of a tetryl primer set off when the torpedo struck the side of a ship (contact exploder), or when it entered the magnetic field of a ship's steel hull (magnetic exploder). Neither type of exploder would operate until the torpedo had run a certain distance, thus protecting the launching vessel from premature explosion.

Mines and torpedoes equipped with the magnetic exploder were successfully exploited by the Germans for a while. Britain and the United States also developed torpedoes fitted with a similar magnetic exploding device. Britain and Germany decided that these magnetic firing devices were too unreliable, and abandoned them early in the war, but the Americans persisted with theirs and experienced a disastrously large number of failures.[2] With the lesson of British experience before them, engineering authorities in Australia decided that the local torpedoes should be equipped with the contact exploder based on an electrically operated pistol. One of the items needed in making the contact exploder was

[2] A great many failures of American torpedoes in the Pacific were attributed to faulty operation of the magnetic exploder. A full account of what is described as one of the great all-time failures of American ordnance is given by Fletcher Pratt, *Atlantic Monthly*, Vol. 186 (1950), p. 25.

an electrical storage battery of high reliability that could be easily charged and had a favourable weight-power ratio. Most suited for this purpose was the nickel-cadmium cell, first developed in Sweden in 1909 but not widely known outside Europe for nearly thirty years. It was unknown in Australia early in the war and attempts were made in the University of Melbourne by Professor Burstall[3] and Dr Heymann[4] to reproduce the cell from one or two samples sent to Australia by the Admiralty. Before they had completed the job, however, supplies of cells arrived from Britain in time to meet the requirements of Australian contractors. As a stand-by, in case insufficient nickel-cadmium cells were forthcoming, Eveready (Australia) Pty Ltd of Sydney made a dry cell that met Admiralty specifications.

Perhaps one of the most striking features of a torpedo was the large space given over to carrying a supply of air to operate its engine and controls. The cylindrical structure with domed ends which was devoted to this purpose was known as the air vessel. A torpedo, unlike most other fuel-power operated devices relying on the surrounding atmosphere, had to carry its own supply of air since after being fired the greater part of its journey to a target was made under water. For every pound of fuel consumed, roughly 15 pounds of air was required. The design of a torpedo was therefore influenced more by the air it carried than by its fuel storage. Substitution of pure oxygen for air considerably reduced the amount of storage space required, but at some sacrifice in safety of handling. The Royal Naval Torpedo Factory at Greenock had produced oxygen-enriched air torpedoes as far back as 1921, and these were used by the British and Australian Navies between the two world wars but because of danger to ships and men they were eventually discarded. The Japanese produced an excellent torpedo of this type with a performance much better than any atmospheric torpedo, and used it successfully; they did not allow humane considerations to deter them.

The air vessel was the largest component of the torpedo. Its over-all length was 4 feet 7 inches, its external diameter 17.69 inches, and the wall at its thinnest was less than a quarter of an inch (0.245 inch, to be precise). Carrying an air pressure of about 3,000 pounds per square inch, the air vessel was a most highly-stressed mechanical device; it had to withstand the pressure and yet be strong enough to survive being dropped from an aircraft. Owing to the need for keeping the total weight of a torpedo to a minimum the factor of safety was kept very low. Nevertheless there could be no failure. The few explosions of torpedo air vessels that occurred in other parts of the world caused most serious accidents, killing many men and severely damaging ships. The unusually small margin of safety that torpedo designers were obliged to accept placed a heavy

[3] A. F. Burstall, PhD, DSc. Prof of Engineering, Univ of Melbourne, 1937-46, King's Coll, Univ of Durham, since 1946. B. Birmingham, Eng, 15 Jan 1902.

[4] E. Heymann, PhD, DSc. Senior Lecturer in Physical Chemistry, Univ of Melbourne, 1938-45, Assoc Prof 1945-49. B. Frankfurt, Germany, 20 Feb 1901. Died 23 Nov 1949.

responsibility on manufacturers and demanded the highest standards of workmanship and materials.

Admiralty specifications for the air vessel called for a nickel-chrome-molybdenum steel with a minimum yield of 60 tons per square inch and an ultimate stress of 69 tons per square inch. Steel of this high quality,[5] which was supplied in the first instance by Melbourne Iron and Steel Mills Pty Ltd and later by the Commonwealth Steel Co Ltd, was forged into a hollow cylindrical shape by means of a 1,500-ton hydraulic forging press at the Government Ordnance Factory at Maribyrnong. This was the first time hollow forgings of such a size had been attempted in Australia. The factory also made the domed ends by a die-forging technique and carried out the heat treatment of both components. The Government Ordnance Factory at Bendigo carried out the machining and grinding operations, all to the exacting standard of dimension and finish imposed by the Naval Inspection Section. The machining to close tolerances of the screw ends of the cylindrical body and the corresponding domed ends was an operation demanding the highest skill. When the air vessels left Bendigo they went to the R.A.N. Torpedo Factory where holes were drilled and tapped for the attachment of the balance chamber and the war head, and the two domed ends were assembled. The latter operation consisted of tinning the already screwed ends of the domes and the cylindrical body and sweating them together by means of a solder seal.

Once it had been fired, a torpedo kept on its set course, since any tendency to deviate was automatically corrected by the gyroscope.[6] This consisted of a perfectly balanced high-tensile brass wheel driven by a powerful jet of air from the air vessel. Since this air was at an extremely high pressure, a reducing valve was used to bring the pressure down to a suitable figure. Under operational conditions the wheel would reach a speed of about 25,000 revolutions per minute within a few seconds. The wheel was mounted in horizontal and vertical gymbals, like a ship's compass, and when not running was free to assume any orientation in space. When running at a high speed the arm of the wheel maintained its direction and any deviation of the torpedo from the path on which it was set at the moment of firing operated a small relay valve (a servometer) which in turn passed compressed air to the air cylinder to operate the vertical rudders through a system of levers. This brought the torpedo back to its set path in such a way that the accuracy of a directional fix was about half a degree.

[5] It was in fact somewhat better: 67-68 tons per sq in yield and up to 74 tons per sq in ultimate strength.

[6] In the days before the torpedo was equipped with the gyroscopic guiding mechanism its performance was far from reliable. The story is told of a South American admiral (Miguel Grau) who tried to torpedo the Chilian ship *Abtao* which he found lying at anchor off Antofagasta. The torpedo's direction was so erratic that at one stage it began heading back towards the admiral's ship. Only by the heroic effort of one of his lieutenants who dived overboard and diverted the torpedo was the admiral's ship saved. Referring to this incident Capt W. W. Davis, RN, relates that "Admiral Grau was so disgusted with the weapon that on his return to Iquique he had the torpedo buried, we hope with full naval honours, in the local cemetery".

The importance of reliability in the gyroscope's performance is well illustrated by the story of the attack of a Japanese midget submarine on U.S.S. *Chicago* anchored off Garden Island in Sydney Harbour, on 31st May 1942. The submarine lay off Bradley's Head, 1,000 yards away. With quiet harbour water and a close, stationary target a direct hit should have been a certainty; yet the torpedo veered to starboard, missing the *Chicago* by a few yards, and finished its run unexploded on the shore of Garden Island.[7] Examination of the gyroscope revealed what appeared to be the source of the *Chicago's* good fortune. The Japanese had, astonishingly enough, been careless in the choice of the material used in the bearings of the gyroscope wheel. They had used a steel which was not adequately resistant to corrosion, and slight rusting had caused the torpedo's gyroscope to deviate and so turn the torpedo from its set path.

The firm of H. A. Chivers, Melbourne, was chosen by the Ordnance Production Directorate to manufacture the gyroscope because it had already had experience in making similar instruments for the aircraft industry. However specifications for a torpedo gyro were far more stringent than those for any gyro used in ships or aircraft. In order to keep the diameter of the balls used in bearings to within plus or minus five-millionths of an inch as was required in the specifications, it was necessary to grade them individually by means of an optical method depending on the interference of light waves. Without procedures such as these and extreme care in machining it was impossible to produce a gyroscope wheel with perfect static and dynamic balance.

It took some time to reach the desired high degree of accuracy in machining the parts, because the manufacturers naturally tended to follow their previous methods and to underestimate the exacting nature of the requirements for a torpedo gyroscope. The necessary high precision was at length achieved and the instruments passed the rigorous inspection tests. The manufacturer commented that "this gyroscope could never have been made by any firm in Australia without the unfailing assistance given by navy officers and inspectors and the technical staff of the Ordnance Production Directorate".

The semi-diesel engine for the torpedo was a four-cylinder radial unit developing 225 horse-power plus or minus 2.5 per cent and weighing not more than 130 pounds—a little more than half a pound per horse-power. General Motors-Holden's Ltd, with their experience in the manufacture of aeroplane engines, were sufficiently confident of their engineering techniques to undertake the manufacture of torpedo engines. For this purpose a special machine shop was built and equipped with metrology and gauge rooms. To compensate for the shortage of skilled artisans the firm made the greatest possible use of high-quality precision machines. Because the engine was cooled by sea water, it was necessary to use

[7] The dangerous task of dismantling this torpedo and rendering it harmless was carried out by Mr E. M. Florence and Mr F. J. Lingard of the Sydney Torpedo Depot. Another torpedo fired by this midget submarine struck a sea wall at Garden Island. The resulting explosion wrecked the depot ship *Kuttabul* moored alongside.

corrosion-resistant materials and alloys, some of which were new to engineering in Australia. A few of the alloys were made with the required physical characteristics by the Austral Bronze Co Pty Ltd, Commonwealth Steel and the B.H.P. The remainder had to be imported from Britain and the United States. One particularly difficult and interesting process was that of "burning on" phosphor bronze pads to the steel connecting rods of the engine. The two metals had to adhere without keys or dovetails, and each was subjected to very great tensile stress to prove adhesion. This was successfully carried out by the firm of A. Wassilief Pty Ltd of Melbourne, sub-contractors to General Motors-Holden's.

Successful aiming of a torpedo depended on an accurate forecast of torpedo speed as well as correct estimation of the range, speed and course of the target ship. An error of 1 knot in 40 in the speed of a torpedo might mean missing the target by hundreds of feet. It was essential, therefore, to keep the speeds of torpedoes within close tolerances, which meant that the engine must have exactly the specified power. The important equipment for testing the engine was supplied in an unexpected fashion. In September 1943, with production due in October, the O.P.D. was informed by navy authorities in Sydney that some equipment had been found for the base testing of torpedoes. This proved to be a complete torpedo engine-testing tank that had been consigned from the R.N. Torpedo Factory in Scotland to the Naval Base at Singapore; the ship had been diverted to Australia after the fall of Singapore. This tank was installed at General Motors-Holden's, and was put to immediate use.

In testing an engine it was run for three minutes completely submerged in water. The first engine so tested proved to have more power than the specifications called for. Because of the very narrow limits within which the speed of a torpedo had to fall, excess power was no advantage. On the contrary it was a defect. Fortunately this was easily remedied by small alterations to the mechanism that controlled the rate of injection of fuel to the engine. Large numbers of engines, sufficient to fill all requirements, were successfully built.

The war head and other major components of the torpedo casing such as the balance chamber, after body and tail unit, were made at the Woodville, South Australia, factory of General Motors-Holden's. Production of these items also called for tolerances seldom achieved in Australia, both in the manufacture of each section and in the final assembly into a complete torpedo.[8] A high standard of sheet-metal-working skill was required in making these sections, in which were to be assembled couplings, bulkheads, doors, valves and many other fittings. General Motors-Holden's made a notable contribution to the torpedo project in producing the casing sections by pressing instead of by the time-honoured, oversea method of hammering out the metal shell.[9]

[8] The sections were assembled at the RAN Torpedo Factory, Sydney.

[9] Although the method of hammering out the metal shell was used in some British factories, others, especially those that before the war had been engaged in making cars, used essentially the technique employed by General Motors-Holden's.

The fuel bottles, which were made by British Tube Mills of Adelaide, were in many respects small-scale versions of the air vessel. They were similar in shape—cylindrical with domed ends—and like the air vessel were relatively light, being made of thin-walled steel of high-tensile strength, yet were capable of withstanding high pressures. Unlike the air vessel they were made all in one piece. They were drawn from "hollows" supplied by Stewarts and Lloyds, with one end formed to shape and rough-machined inside and out. Then followed the difficult operation of closing the open end and at the same time forming a heavy neck. Finally the bottles were re-machined inside and out. Machining a hemispherical end through a relatively small hole was difficult enough, but done to a high degree of precision it was an outstanding feat. It is only fair to add that machines already tooled up for these operations were obtained from the United Kingdom.

Three firms collaborated to produce the transmission gear for driving the contra-rotating propellers of the torpedo.[1] The shafts were essentially tubes, one inside the other, which were given opposite rotating motions by means of bevel gearing which in turn was driven by the uni-directional rotation of the engine crankshaft. The inner propeller tube also served as the exhaust from the engine. The accuracy demanded in making certain components of the transmission gear was such that prominent Australian gauge makers believed it impossible to make gauges to the tolerances required to test these components. After some concentrated effort, however, the staff of the Adelaide School of Mines and of the Engineering School of the University of Melbourne succeeded in making the gauges.

Brief reference must be made to the work of Gibb and Miller Ltd of Adelaide, who made the four-stage air compressors (a vital piece of ancillary equipment) capable of operating to pressures of 3,800 pounds per square inch. These units, complete with engine, radiators, separating columns, intercoolers and associated gear, and mounted on trailers, were turned out at the rate of one every ten days for over a year.

Torpedoes contained an extraordinary number of screwed components which because of their high precision required the use of ground-thread taps, dies and chasers. The production of these ground-thread taps and the equally accurate threading dies presented no insuperable difficulties to local tap and die makers; the main difficulty experienced was the lack of thread-grinding machines—machines which were wonderfully accurate and very costly. To ease the situation in regard to cutting tools for this project, Britain supplied a number for use by Australian manufacturers. Although gauge and machine-tool making facilities were extremely hard pressed at the time firms usually managed to solve their own problems. In special projects such as heat treatment of alloys (of steel for springs in gyroscopes, for example) and in the problems of high-pressure castings, help was given by the Munitions Supply Laboratories. These laboratories, together with

[1] The firms were Johns and Waygood Ltd, Richardson Gears Ltd, and H. V. McKay-Massey Harris Ltd.

the National Standards Laboratory, gave valuable help in making and checking screw gauges.

Ordinary castings of bronze, normally quite porous and liable to leak under any appreciable pressure, were quite unsuitable for torpedoes, for which castings must be capable of withstanding pressures well above 3,000 pounds per square inch. Non-ferrous castings of this quality were made by Duncan and Ling, Purvis Glover and Russell Manufacturing of Melbourne; by Davies Shephard (Sydney) Pty Ltd; and by Scott Bonnar Ltd of Adelaide. The oil bottle, the highest pressure non-ferrous casting in the torpedo, was cast by Davies Shephard without difficulty.

As the major assemblies were completed they were sent to the Torpedo Factory for final assembly. This was much more than merely screwing parts together; parts had to be machined, fitted, adjusted and tested, and overall tolerances of dimensions had to be maintained. About 200 civilian workers were employed on this phase of manufacture, as compared with about 2,000 employed by the major contracting firms making assemblies. The number of people working indirectly on the torpedo project through sub-contractors ran into thousands.

The final and most important of all the tests applied to a torpedo was ranging, which consisted of firing it from a discharge tube located on shore over a carefully selected stretch of water. During ranging the war head was replaced by a dummy head filled with water. At the end of the run the water was expelled and replaced by air, which caused the torpedo to float upright and so made it easy to recover. The direction, depth and speed were closely observed and noted with special instruments.

A range surveyed by the Hydrographic Branch of the R.A.N. was set up at Pittwater, in Broken Bay, 30 miles north of Sydney. Firing tubes, observation station, workshop, pier and target rafts were designed and erected while the torpedoes were being made. Normally every torpedo was ranged twice.

The ranging of the first Australian-made torpedo at Pittwater on 24th February 1944 was a signal success; it sailed straight through all Admiralty tests without needing any of the small adjustments that are often called for in a first trial. The range officer, Lieutenant Owens,[2] reported, "the performance of this torpedo could not be bettered".

The first air ranging tests, conducted in July 1944 at Jervis Bay, were also highly successful. Some time later, referring to the Australian torpedo, the Admiralty reported: "The general condition of these torpedoes was very satisfactory, the finish being of good quality and the workmanship of a very high standard; the whole project compared very favourably with the British-produced torpedo."

An important factor in attaining these very high standards was the system of inspection. Standards as strict as any ever set for Australian

[2] Lieut (E) J. D. Owens, MBE; RAN. Officer-in-Charge of RAN Torpedo Depot at Garden Island 1940-43; served subsequently in ships and naval establishments until his death on 21 Oct 1944. Of Willoughby, NSW; b. Sydney, 19 Sep 1887.

engineering up to that time were relentlessly and efficiently imposed and no small amount of credit for the achievement of successful torpedo manufacture must go to the staff of Navy Inspection. In the drive to attain these standards in the workshops the sound practical experience of Mr Florence as superintending foreman and Mr Wilkie[3] as chief draughtsman was invaluable.

The ranging tests marked the climax of two years' unremitting toil on one of the most outstanding examples of precision engineering undertaken by the Commonwealth. Using mainly Australian materials and tools, Australian engineers and skilled workmen with the help of a small band of British experts did a splendid job. Ten years after the war the R.A.N. Torpedo Factory was still the only one in the British Commonwealth outside the British Isles.[4]

This record would be incomplete without some mention of the contribution of women, who made up about 25 per cent of the skilled workers employed in the Torpedo Factory. By reason of their greater patience and their sometimes more highly developed mechanical sense, women proved themselves capable of carrying out a number of processes more efficiently than men. The quality of the work on propellers, much of which was done by women, was such that none ever required adjustment after being assembled.

Torpedoes, like most complex mechanisms, required continuous servicing. For this purpose tools to adjust, remove or dismantle the various parts were required for depots and for bases in the forward areas. Responsibility for organising the provision of tools, some of which had to be specially designed, was accepted by the Victorian Automotive Chamber of Commerce, which placed the bulk of its orders with hundreds of motor garages and service stations throughout the State.

It is perhaps something of an anti-climax to have to record that Australian-made torpedoes were never used in action. Even before the first torpedo had come off the assembly line the tide of battle in the Pacific had turned so far in our favour that the orders from the Admiralty and the R.A.A.F. were drastically reduced. Naval successes in the Pacific in the second half of 1942 made it possible to maintain lines of communication and outside supplies of torpedoes could therefore be obtained. Their local manufacture became not only unnecessary but actually undesirable since our resources could be used more profitably in other directions. For the remainder of the war the R.A.N. Torpedo Factory was therefore devoted mainly to the maintenance and repair of torpedoes for the British Pacific Fleet and the United States and Netherlands Navies as well as for the Royal Australian Navy.

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[3] J. F. Wilkie. Apprentice and then draughtsman RN Torpedo Factory, Greenock, 1932-42; Chief Draughtsman RAN Torpedo Factory 1942-45. Of Greenock, Scotland; b. Greenock, 8 Jul 1916.

[4] In compiling this chapter the author was greatly helped by the cooperation of Engr Capt R. Berry-Smith and senior members of his staff, and by Capt L. A. W. Spooner, Engr Capt A. C. W. Mears, and Mr J. H. Poulton.

When contracting firms had ceased to manufacture assemblies, many of the machine tools supplied to them, such as jigs, tools and fixtures, were transferred to and installed in the Torpedo Factory, thus enabling practically the whole of the manufacturing process to be carried out under the one roof. Not long after the war in the Pacific ended civic authorities (of the North Sydney Municipality) became anxious to discover what was to happen to the factory. Much to their astonishment they learned that its activities, though altered in character, were to continue indefinitely. The factory was slowly turned over from assembling to complete manufacture. Some years after the war it began to make the 21-inch torpedo—the largest in use by the British Navy—not in any great number, but sufficient to keep the torpedo-making technique alive and in a condition to profit by new technical and scientific discoveries.

MINES

The suggestion that Australia should undertake the manufacture of moored contact mines was first made to the Commonwealth Naval Board by the Admiralty as long ago as 1923. One of the arguments advanced was that the establishment of local manufacture might act as a deterrent to a possible enemy. Where the geographical position admits of their use, as it does in Australia, the laying of fields of mines is one of the cheapest methods of defending harbours, ports, navigable rivers and sea lanes. At the time the Admiralty made its proposal, the laying of submarine mines was a responsibility of the army. Not until the following year did the Australian Council of Defence, in response to repeated requests, transfer the responsibility to the navy. This, however, had little effect on the fate of the Admiralty's proposal. The Munitions Supply Board investigated the existing engineering facilities for manufacture of mines, and finding them inadequate, recommended that the project should be postponed. It considered that any attempt to make mines in Australia at this period would have proved far too costly; indeed the Naval Board held the view that far from being able to meet the cost of manufacturing mines, it could not even afford to pay for the care and maintenance of the 2,000 mines it had acquired from the United Kingdom after the 1914-18 war. There the matter rested until September 1935 when the Admiralty revived its proposal.

This time the Munitions Supply Board was more optimistic about the prospects of manufacture and suggested that the Admiralty should be asked for drawings and designs of the latest contact mines. These, when received from the Mining School at Portsmouth, England, should have formed a sufficient basis for reaching a decision, but despite this investigations continued half-heartedly, and in December 1937 it was reported to Whitehall that the manufacture of mines in Australia was still impracticable owing to lack of factory accommodation and to the fact that the Munitions Supply Board had not made provision to supply the requisite quantities of T.N.T. for filling the mines. "The position," the report added, "will be re-examined in twelve months." Before this period had elapsed

alarm at the political situation in Europe galvanised Australian defence authorities into action.

Since the manufacture of mines was beyond the facilities then existing in the government factories, it was proposed that the Government should build a special factory for the purpose. The Admiralty considered this scheme to be unsound. A more economical plan, in their opinion, was to establish, in appropriate industries, facilities which in wartime could be rapidly turned round to supply components of mines. On 15th August 1938 the Naval Board, having been assured that the Admiralty was willing to place an educational order for 500 mines intended for use outside Australia, inquired whether the Ford Motor Company at Geelong would undertake their manufacture.

Several reasons lay behind the choice of the Ford Motor Company: firstly, as a manufacturer of car bodies, it was experienced in the field of metal pressing, especially of sheets of heavy gauge—an operation that would be needed in the fabrication of the hollow body of the mine itself; secondly the company had a tool-room which was particularly well equipped for the kind of work that would be required in the manufacture of components for mines; thirdly, it had sufficient spare equipment to enable an early try-out of the main processes of manufacture. Moreover it had in the course of its ordinary peacetime activities acquired some experience in methods of mass production and in the operation of assembly lines. Most of the senior executives (the Australian company was founded in 1925) were Canadians who had been trained either in the Ford Company in Canada or in the parent company at Detroit.

The type of mine being considered for manufacture (known officially as Mark XIV Contact Mine) consisted of a hollow metal sphere 40 inches in diameter containing a charge of T.N.T. and a mechanism for exploding it. Part of this mechanism took the form of a horn or spike protruding from the metal sphere. Each horn (there were six in all) consisted of a sealed glass tube surrounded by a rubber sheath, the whole being protected by a metal tube. The glass tube, containing a solution of sulphuric acid and potassium dichromate, was fixed at a quarter of an inch from a battery consisting of a zinc cup and carbon ball. When the horn with the protecting metal tube removed was struck, the sealed glass was shattered and perforations in a rubber envelope allowed the liquid contents to run into the battery. The solution of sulphuric acid and potassium dichromate completed the battery, thus closing the circuit between the zinc and carbon. The resulting current from the battery excited the primer which then set off the main charge.

Each mine was accompanied by a sinker. The main part of the sinker consisted of a rectangular box with a seat on which to rest the mine shell while awaiting launching. The box was originally specified as a welded structure but permission was granted to rivet the box of the Australian mine sinkers. Internally the box contained the cable-holding reel and the depth-setting mechanism which governed the amount of cable paid off to regulate the depth at which the mine would be set. Externally were

several attachments including the anchor and a ball weight releasing the action of the depth-setting mechanism.

After somewhat protracted negotiations, during which complete manufacturing details supplied by the Admiralty were fully examined and used as a basis for a rough forecast of manufacturing costs, an agreement was reached by which the Commonwealth Government undertook to build and equip an annexe on land donated by the Ford Company. Many components of the mine and its ancillary equipment, such as castings and forgings, wire rope, glass tubing (for mine horns) and electrical switch gear, were to be made by other firms specialising in the processes required for their manufacture. The annexe was designed in the main for the completion of some principal components, their sub-assembly, and the final assembly of the mine itself; it was also designed to carry out such operations as heavy pressing and some forms of machining for which the company's main plant was not really suitable. Several stages in the manufacture of mines were carried out in the company's own works, so that in practice the arrangements finally adopted were a compromise between the proposals that had been made to set up a special government factory and the Admiralty's suggestion to use the existing facilities of commercial industry.

On 10th October 1938, during a meeting at Victoria Barracks (Melbourne) at which representatives of the Ford Company and the Principal Supply Officers' Committee, and the Inspector of Naval Ordnance, were present, the Ford Company was asked to prepare estimates for the buildings, machine tools, dies, jigs and fixtures needed to produce mines at the rate of 6,000 per year, and to quote for a trial order of 500. Nearly a year elapsed before the first firm order was placed for 500 mines.

Orders were placed both in the United Kingdom and in the United States for machine tools, and construction of the annexe was begun early in October 1939. Within about six months the building itself was completed and machine tools began to arrive in reasonable numbers, mainly from the United States. The Ford Company was fortunate in possessing a sufficiently powerful metal press, and in July 1940 it was able to begin manufacture of the mine shell without waiting for a press that had been ordered specially for this purpose.

Plans were made to meet the Admiralty's educational order of 500 mines within about a year and at the same time to build up facilities for an output of 3,000 a year. By way of giving some guarantee that these enlarged facilities would be used, the Admiralty informed the Naval Board in April 1940 that a further order for 1,000 would be placed provided the mines could be filled with T.N.T. in Australia and sent direct to Singapore or Hong Kong, and provided that filling the mines would not create a shortage of T.N.T. in Australia. On receiving an assurance that these provisos could be satisfied the Admiralty confirmed the order.

The scale of the planned production of mines was enlarged as the war progressed. Local manufacture of mines had in the first instance been established purely on the initiative of the Admiralty, which was anxious

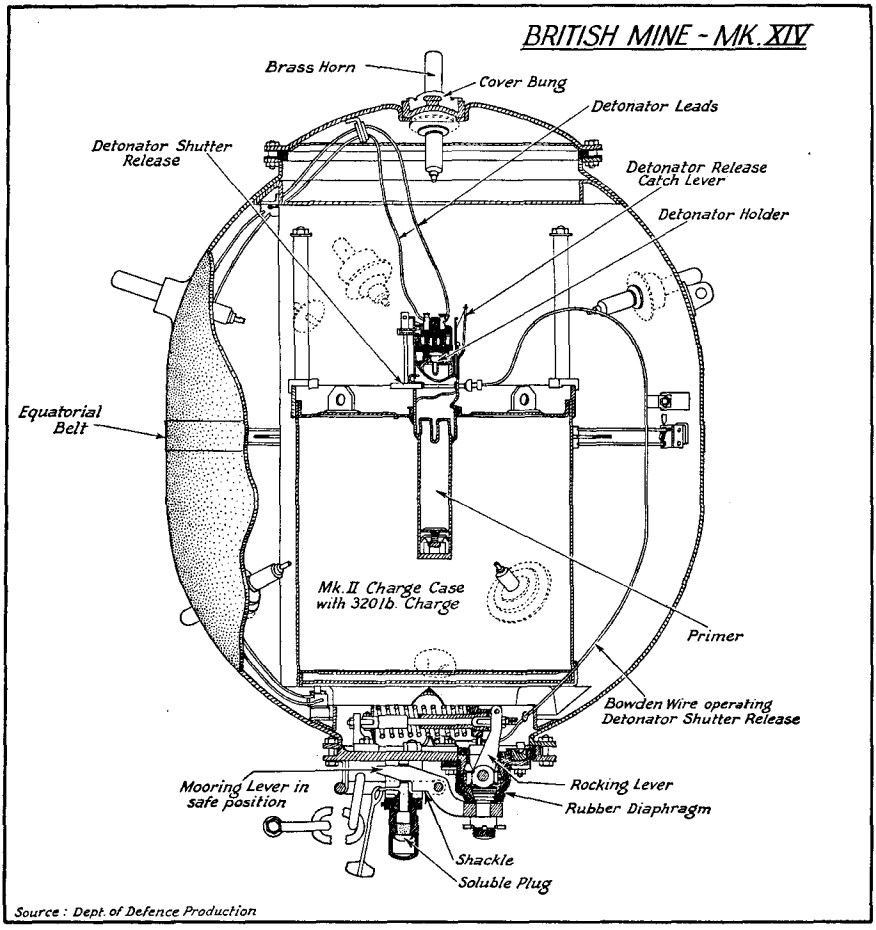
to safeguard its requirements in the Far East. Until 1940 the possibility of mining Australian waters with Australian-made mines had not been considered seriously by the Naval Board, but during the latter part of that year the board, in revising its estimates of the number of mines likely to be needed, decided that plans should be made for defensive minelaying round Australia to meet the possible extension of the war to the Far East. In that event defensive minefields would be required for Port Moresby, Darwin and Fremantle, though opinions differed about the necessity for mining Fremantle. As soon as this policy had been approved by the War Cabinet the Naval Board placed an order for 3,500 mines, to be stored when complete at Swan Island in Port Phillip Bay.

Although the process of making a contact mine was neither so complex nor so exacting as that of making a torpedo, it was not without interest. One of the principal operations was the manufacture of the steel shell, which was built up from two hemispheres joined by an equatorial belt. British practice, as called for in Admiralty specifications, was to press the hemispheres from hot sheets of mild steel three sixteenths of an inch thick. Engineers of the Ford Company were convinced that it would be easier and more effective to cold press the hemispheres, and asked permission to do this. The matter was referred to the Admiralty, for whom the mines were being made, and permission was granted on condition that the cold-pressed hemispheres met the approval of the Australian inspection service. After some delay and difficulties Fords produced a number of sample hemispheres which satisfied the specifications, and in December 1940 Navy Inspection gave approval for the large-scale manufacture of cold-pressed hemispheres.

After the metal hemispheres had been pressed out a good deal of work remained to be done on them, such as drilling (or flame-cutting) to accommodate the horns, eyebolts and other attachments. When all this work, carried out on an assembly line, had been completed, the two hemispheres, together with the equatorial belt (see diagram), were lowered into a jig ready for the final welding. This operation was completed with a speed of about 30 inches per minute, an indication that the welding techniques used in mine construction had reached a high degree of efficiency.

Some of the operations carried out on the assembly line offered more than ordinary difficulties, the most notable being the welding of the threaded boss of the contact horn into the mine shell. Under the heat of welding, the high precision thread—so made to give a watertight fit with the plug gauge to be screwed into it—suffered severe distortion and could no longer accommodate the plug gauge. Losses caused through unacceptable horn bosses meant the rejection of the whole hemisphere and the disorganisation of the production line. By carefully controlling the conditions of welding—such as the rate of deposit of metal and the temperature of the weld—it was found possible to adjust the tolerance of the thread so as to overcome the effect of any distortion that might be produced.

A contact mine was not a highly complicated weapon, yet despite the fact that the Ford Engineering Company made 407 out of the 477 components for the mine, the services of some 65 additional firms were required in making other special parts. These firms had troubles of their



own. None contains a more interesting lesson than the trouble experienced by Australian Consolidated Industries in manufacturing a minor but vital component, namely the glass container in the contact horn.

If not correctly treated, glass could behave most capriciously; improperly annealed, for example, it might crack spontaneously and without warning. Glass was a notch-sensitive material, which meant that if it contained flaws or was accidentally scratched it might yield to abnormally low stresses. The small glass tube which played such an important part in exploding the mine had therefore to be of the highest quality and conform to the strictest specifications. A weak glass tube in any one horn of

a mine might, if other safeguards failed, cause the total destruction of a minelayer and its crew; this did in fact happen during the war of 1914-18. In the same war millions of pounds were spent on a barrage of mines stretching right across the North Sea, which was intended to stop German submarines moving northwards. So many of these mines exploded on laying that the barrage was virtually useless. Because of such incidents as these naval inspection of glass tubing was understandably rigid.

There was no technical difficulty in making glass tubes of the size and shape required, but there was great difficulty in satisfying inspection authorities about the strength and reliability of the tubes. The first glass used for the purpose by the contracting companies (New Air Pty Ltd, Neon Signs Ltd and G. Herring and Co) was a heat-resistant soda glass ("Firetex") made by Australian Consolidated Industries in 1937. When they first began to make tubes, the contractors had not been able to keep up a satisfactory rate of delivery, and for this they blamed the quality of the tubing supplied to them by the glass manufacturers. On the other hand, glass experts of Australian Consolidated Industries were convinced that the high percentage of tubes being rejected (in the region of 93 per cent) was due to unnecessarily rigid inspection. In the hope of finding a way out of the impasse the whole task of supplying and processing the tubing was transferred to Australian Consolidated Industries, who set about producing tubing of a still higher standard, which it proved, to the satisfaction of the Department of Munitions, to be superior to "Bishop's Adamant", the best type of boiler gauge glass tubing. It was therefore disappointing to find that the introduction of this new type of glass resulted in an increase in the number of tubes rejected. Compared with losses and waste in some parts of the munitions program the economic losses involved in the rejection of the glass itself were insignificant. What was significant was the fact that the whole output of mines could have been threatened by disputes over inspection.

Part of the trouble, the glass experts contended, arose from the wording of the specification. For example: "Presence of cracks, marked bubbles, stones, pronounced surface lines or cracks which are not shallow will involve rejection. The scratch is considered to be very light if it is not detected readily when the finger nail is passed over it lightly. . . . If the bubbles are small and resemble spots rather than bubbles, tubes are acceptable, but tubes with bubbles easily discernible as such will be rejected." It is not difficult to imagine that arguments could arise from such a specification. What does "easily discernible" mean: with the naked eye, a single lens, or under a microscope? Even the polariscope tests for strain arising from imperfect annealing were the subject of argument, especially as they concerned tubes considered to be on the borderline of acceptability.

In the hope of clarifying the position the glass experts appealed to the Department of Munitions to appoint a "competent higher scientific authority" to arbitrate between them and Naval Inspection. This move was treated with scorn by the inspection authorities, who had open to them

the scientific resources of the Australian universities and the C.S.I.R., and also, if the issues could not be resolved locally, those of the British Admiralty. It would have been difficult in the first place to find a higher scientific authority and then to persuade him to accept full responsibility for the safety and efficiency of a store to be used on His Majesty's ships if faced with opposition from Naval Inspection backed by its scientific advisers and the British Admiralty. On the other hand, there was this to be said in support of the glass manufacturers' point of view. They wanted something more precise than visual inspection—such, for instance, as pressure tests—and they wanted to be told more exactly what the tubing had to stand up to. Early in 1943 Naval Inspection authorities acceded to the company's wishes by carrying out pressure tests, the results of which satisfied both parties. That the inspection authorities did their work well is borne out by the absence of accidental explosions in mines in Australia during the war of 1939-45.

The clashes between inspectors and manufacturers which have been described at some length in this chapter were not peculiar to the manufacture of mines and torpedoes. In varying degrees of intensity they occurred with almost every kind of munition. The truth was that before 1939 very few Australian firms had had the experience of working to detailed specifications under careful and unbiased inspection. At the end of the war most firms were ready to admit how much their techniques had improved and how much they had learned by working under such conditions. Once the firms engaged in manufacturing mine components had gained the confidence of Naval Inspection they did a fine job. Australian-made mines achieved a high degree of efficiency, comparable with that of the same types made in Britain.

The completed mine units (shell and sinker) from the annexe at Geelong, and the charge cases which had been filled with T.N.T. at Maribyrnong, were taken to the Mine Depot at Swan Island, Victoria, where each mine was assembled and "married" to the sinker before it was loaded into the minelayer. Australian-made mines were laid round New Zealand by H.M.A.S. *Bungaree,* which also laid defensive fields round Noumea and along the Great Barrier Reef.[5]

By November 1944 the demand for mines had so far diminished that the annexe greatly reduced the scale of its activities. It did not cease altogether until shortly after the war, when all the Commonwealth-owned equipment essential for the production of mines was transferred to the Ordnance Factory at Maribyrnong.

[5] The production figures for mines were:

1941	1,639
1942	4,563
1943	5,210
1944	1,575
	12,987

CHAPTER 14

ARMOURED FIGHTING VEHICLES

AS frequently happens with important inventions, the basic principle of the tank occurred to a number of people independently and about the same time. Among them was an Australian inventor, L. E. de Mole,[1] who in 1912 made and reduced to practical shape a brilliant invention which anticipated and in some respects surpassed the one actually adopted several years later.[2] De Mole despatched blueprints of his invention to the British War Office, which acknowledged them, pigeon-holed them and forgot them. Several years later Sir William Tritton and Major W. G. Wilson submitted to the War Office a design which on being accepted, became the basis of the British tank used in the first world war. On learning that the Royal Commission on War Inventions had awarded Tritton and Wilson £15,000 for their design, de Mole applied for recognition of his invention and travelled to England for the purpose of supporting his claim. He was granted £965 to cover out-of-pocket expenses, and was decorated.

In the later years of the first world war Britain introduced the tank into warfare and at length built up a tank force so large that in the final offensives in France as many as fourteen battalions were employed (a big force even by the standards of 1940 and early 1941). British officers and designers continued to develop the tank and to work out doctrines of armoured warfare. During the twenties and thirties little money was made available to produce tanks in quantity in Britain. When Germany began to rearm, her leaders, impressed by the work and writings of such British designers and strategists as Giffard Martel, J. F. C. Fuller, and Liddell Hart, gradually built up a fairly large tank army and resolved to use it in mass as the British military experts advocated. By 1939, Germany had far larger armoured forces than her enemies. The success of the German armoured divisions in Belgium and France demonstrated afresh the power of the tank.

Even before this demonstration the Australian Army, which had maintained a tank training corps since 1935, began to consider whether tanks should be made in Australia. Australian representatives, including Major-General Northcott, who attended the first Dominion War Conference in London in October 1939 and who afterwards inspected the defence systems of Britain and France, returned fully convinced by what they had seen in Europe that Australia would be compelled to make most of her own military equipment. Soon after the fall of France the Department of Defence decided that an attempt should be made to manufacture tanks,

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[1] L. E. de Mole, CBE. (Served 1st AIF.) Engineer; of Melbourne and Sydney; b. Adelaide, 13 Mar 1880. Died May 1950.

[2] See *Proceedings of the Royal Commission on Awards to Inventors*, HM Stationery Office. Leonardo da Vinci has been credited with the first conception of the tank.

and forwarded a recommendation to this effect to the War Cabinet, at the same time placing an order for 859.

In making its recommendation to the War Cabinet it was the army's intention that in the first instance Australia should attempt to provide tanks for the A.I.F. in the Middle East, where armoured vehicles of all kinds were sadly lacking not only among Australian but among British forces as well.[3] Britain's factories were then fully occupied in preparing to meet the threatened invasion of her own shores and there was no better hope of obtaining tanks from the United States, despite the fact that its vast automotive industry was turning to the production of armoured fighting vehicles. That tanks might also be required for the defence of Australia in the event of Japan entering the war was a possibility to which military planners were fully alive.

For a country that had not yet manufactured a motor-car—a much less difficult undertaking—this was technically a most ambitious program, and the serious strain which it was likely to impose on Australian engineering industry led to the growth of two schools of opinion: one opposed to the manufacture of tanks on the ground that it was beyond Australia's engineering capacity, the other convinced equally firmly that the challenge could be met. The Australian Army leaders' enthusiasm for the tank project was, from the beginning, shared by the Department of Munitions. Much later, when the manufacture of tanks in Australia came under criticism from Lend-Lease authorities, it also received the support of General MacArthur, who in a letter to the Prime Minister said: "I am most heartily in agreement with the proposal that Australia should have a tank production program." In addition to opposition within Australia there was in some quarters in Britain and the United States a strong disinclination to believe that Australian industry was capable of making tanks. Among the early civilian optimists was Sir Langdon Bonython, who, to encourage the Commonwealth Government in its efforts to launch tank manufacture, had made a gift of £25,000 for the express purpose of assisting investigations of tank design.

The cruiser tank was only one of a number of armoured fighting vehicles eventually required by the army. There were also machine-gun carriers, two-pounder anti-tank gun carriers, three-inch mortar carriers, scout cars, light armoured cars, heavy armoured cars, and heavy (infantry) tanks.

The general plan was to make the army responsible for the designs of these vehicles, and the Department of Munitions (through the Directorate of Ordnance Production) responsible for manufacture. With these ends in view the army set up a Design Section within the Branch of the Chief Military Adviser, and the Ordnance Production Directorate created a

[8] At the end of 1940 sprocket and track parts were made in Australia for the British cruiser tanks, and were sent to the Middle East. It was unfortunate, in view of the critical stage of the campaign and the urgent need for these parts, that they should have proved completely useless. The reason for this was found to be that the drawings sent out from Britain to the Australian contractor were not up to date and did not include the modifications that had been incorporated in the tracks manufactured in England. When this was realised the drawings were altered appropriately, and a second large order from the British Ministry of Supply was satisfactorily completed by the contractor, Messrs H. V. McKay-Massey Harris.

Section of Armoured Fighting Vehicles.[4] The section's first task was to explore the general problems of production and to coordinate the development of army design with the manufacturing capacity and raw materials available. To ensure the closest cooperation between the two sections arrangements were made for their staffs to work under the one roof—the Crace Buildings in Melbourne.

The tank is singled out from other armoured fighting vehicles for a detailed account because its manufacture presented the greatest challenge to industry.[5]

Normal procedure in making a complex piece of equipment such as a tank was first to compile a "user specification" outlining the general requirements, such as the degree of protection, speed, armament, number of crew, range of activity, communication equipment and automotive performance—a complex document which could be drawn up only by combat officers, and must be interpreted by experienced technical officers of the Army General Staff. After problems concerning these requirements had been thoroughly thrashed out a workable design was produced. Concurrently, full-size models in wood ("mock-ups") were built in order to assist designers and users to determine the most efficient disposition of the numerous pieces of equipment which must be accessibly packed in the vehicle: ammunition, radio, small arms, operating mechanism and controls, to mention only a few. A fully-operative prototype, or pilot model, was built, then tested, and if necessary modified until it was as nearly certain as possible that it would do what was expected of it. At this stage the design was "frozen". Then, and only then, was mass production undertaken. In war, these orderly steps in design and production were often too time-consuming to be carried out in the normal sequence, with the result that frequently they had to be overlapped.

Design in itself was a complex process in which a number of distinct stages might be recognised. The first step to decide upon was the basic design, which was essentially an elaboration of the user specification. The next step comprised the basic engineering design, which delineated the way the user specification was to be implemented—the nature of the power unit, for example.

This was followed by the detailed engineering design entailing the drawing up of the dimensions of every component in the vehicle, ranging from nuts and bolts to the engine and armour plate. It involved fixing not only the size, shape and weight of every part but also the degree of tolerance or permissible variation from these dimensions, which in turn required on the part of the designer a thorough knowledge of modern mass-production methods and interchangeability of components.

Then followed the detailed design of tools, jigs, gauges and fixtures necessary to produce the components in quantity with provision for interchangeability. As already pointed out, under ideal conditions these steps

[4] It was later (in July 1941) renamed the Armoured Fighting Vehicles Division.

[5] In writing the story of the Australian tank I was greatly helped by Mr H. J. Bromley and Professor C. H. Munro.

were taken in the order outlined, but simultaneously with any one or with all four a review had to be made of manufacturing capacity to ensure that the components designed could be made in the time required from available resources of materials and machine tools.

The General Staff memorandum on the proposed Australian Cruiser Tank issued on 11th November 1940 stated that:

> Tanks are required to operate in and disrupt the organisation of hostile rear areas, thus virtually isolating the troops in forward areas and severely reducing their powers of resistance. In order to achieve this object tanks may be forced to break through a defensive area which has been organised and prepared to meet such an eventuality. Whether this is necessary or not, it has become inevitable in modern war that deep penetration by armoured forces will be met, and counter-attacked, by the armoured forces of the defending army.
>
> For their operations in rear areas, the attacking tanks must be prepared to engage unarmoured troops who may defend themselves with obstacles and anti-tank weapons.
>
> The tank must therefore possess considerable immunity from the fire of anti-tank weapons and from field artillery which is prepared to engage tanks in the vicinity. This partial immunity is achieved by a combination of speed and armour. The natural development, greatly accelerated since the outbreak of war, has been to increase the hitting power of anti-tank weapons, including those carried on tanks. This necessitates an increase in armour provided no reduction in performance is entailed; otherwise the slower moving vehicles will be outmanoeuvred in tank-versus-tank actions.
>
> The tank must carry a weapon with which to engage hostile tanks and also weapons of the anti-personnel type. Thinly armoured tanks can receive their *coup-de-grâce* so easily from those better protected that the whole basis of their tactics is destroyed. They would be unable to carry out their role. The pre-war conception of fast, lightly armoured tanks for reconnaissance has not withstood the rapid development of tank and anti-tank weapons. The War Office has advised that inadequately armoured tanks are a death trap.

Essentially what the army required was a tank weighing between 25 and 30 tons, mounting a two-pounder gun as the main armament, with supplementary armament of one or two Vickers .303 machine guns, a crew of four or five according to armament, minimum range of action of 150 miles, speed of 30 miles per hour and covering equivalent to the protection of 50-millimetre armour plate, proof against two-pounder anti-tank guns at close range.

As soon as the country was committed to making tanks, two important steps were taken. An Ordnance Production engineer, Mr A. Chamberlain, was immediately sent to the United States to collect the latest information on tank production in that country. About the same time the Commonwealth Government, aware that there was no one in Australia with extensive experience in tank design, made an urgent request to the British War Office for the services of engineers skilled in the design of tanks. In reply, the War Office put forward the name of Colonel Watson,[6] and the offer of his services was immediately accepted. Watson, who had been an artillery officer in the first world war, had spent his life since then

[6] Col W. D. Watson, OBE, MC. (Royal Artillery 1914-18.) Vice-President, Mechanisation Board, Ministry of Supply, 1939-40; Chief of Design, AFV Producn, Australia, from 1941. Regular soldier; b. 16 Jan 1893.

studying problems of tank design and was eminently well fitted for the task for which he had been chosen. On his way to Australia he visited the United States, where, in company with Chamberlain, he made a close study of the American medium tank, M.3, the tank which, although then untried on the battlefield, was selected by the Ordnance Production Directorate as the one most likely to meet the requirements set out in the General Staff's memorandum.

The tank project received a new impetus when, shortly after his arrival in Australia in December 1940, Watson was made technical adviser to the newly created Army Design Directorate. It soon became evident that an experienced hand was at the helm. He quickly modified the army's user specification to conform with the British views on the necessity of a low silhouette, and as it became clear that it would not be possible to copy the M.3 at all closely, he proceeded to carry out the basic design of what subsequently became known as the Australian Cruiser Tank Mark I (A.C.1), a much heavier tank than was originally contemplated by the army. Watson's preference for a heavier tank was supported by General Mackay,[7] who said in the course of a radio broadcast: "If Australia is to send many more men overseas to fight in the future, she must also produce and send heavy tanks for them to fight with."

In the widest and most general terms, four main engineering problems confronted tank designers and manufacturers. Since the tank had to be heavily armoured, there was the problem of deciding firstly what kind of steel should be used for armour; secondly how it should be produced; and thirdly, whether it should be rolled and welded or riveted, or whether it should be cast. Lastly, there was the problem of designing the power unit, which would clearly have to be based on imported engines.

Settling these questions was to prove a lengthy business. Experience with British tanks on the Continent early in the war had shown up defects; consequently there was no ideal, thoroughly-tested Allied tank upon which an Australian tank might be modelled. In point of fact, just as Watson was beginning his work in Australia, a British mission was discussing problems of tank design and production with ordnance experts in the United States.

Formulation and production of steels suitable for armour of the tank were assigned to metallurgists of the Commonwealth Steel Company and the Broken Hill Proprietary Company Ltd. Preliminary investigation of the resources of Australian industry showed that owing to serious limitations in the steel industry's capacity to roll plate of the thickness and size used in oversea tanks, it would be impossible to copy a British or American tank in its entirety. This limitation was due not to the industry's inability to carry out the kind of rolling operation required, but to the fact that the machines capable of doing it were already fully occupied with munitions work. The only alternative seemed to be to cast the armour plate. Furthermore, the power unit with which the American M.3 was

[7] Lt-Gen Sir Iven Mackay, KBE, CMG, DSO. (1st AIF: Comd 4 Bn 1916-17, 1 MG Bn 1918, 1 Inf Bde 1918-19.) GOC 6 Div 1940-41; GOC-in-C Home Forces 1941-42; GOC Second Army 1942-43. High Commnr for Aust in India 1944-48. Schoolmaster; of Sydney; b. Grafton, NSW, 7 Apr 1882.

fitted was not available in Australia, nor were there any prospects of importing it. For these reasons a basically new engineering design of the power unit had to be worked out.

In attempting to assess the difficulty of making tanks in Australia the improvisations forced on designers must be borne in mind. These circumstances differentiated the tank project from practically every other munitions project undertaken in Australia during the war. For guns, ammunition, aircraft, torpedoes and mines the basic design and detailed engineering designs were, with few exceptions, carried out overseas; in many instances Australian manufacturers were even supplied with the detailed designs of tools, gauges and fixtures necessary to produce component parts in large quantities. The tank, on the other hand, had to be almost entirely redesigned.

One of the main problems met by designers of the power unit was to adapt automotive engines for use in driving a heavy vehicle such as a tank. Cadillac engines, which could at that time be imported without difficulty, appeared to lend themselves to this kind of adaptation.[8] Despite opinions to the contrary held by a number of engineers, including some from the General Motors Corporation in the United States, Mr Code[9] (Chairman of the Automotive Engineering Panel) and Professor Burstall (of the University of Melbourne) strongly supported the idea of using Cadillac engines. The indecision that prevailed in the early days of the project regarding the best method of providing power for the tank is now quite understandable. Unlike Germany, neither Britain nor the United States had, before the war, designed and produced an engine powerful enough or compact enough to fit into a 30-ton tank designed to travel at 30 miles an hour and to be capable of climbing out of deep ditches. As late as 1943 the United States, with all its great industrial resources, was still in process of developing, from several alternatives, a really satisfactory tank engine, and was obliged to use unsuitable aircraft engines in its early models. Australian designers were also compelled to improvise. They finally decided to adapt 1940-model Cadillac motor car petrol engines for the purpose by combining several engines into a single power unit—an innovation in tank design that had not been attempted elsewhere.

Having examined general drawings for the tank, the Ordnance Production Directorate expressed doubts whether Australian industry was capable of producing the intricate synchromesh gears that would be required if the design suggested by the army was adhered to. This gear box was one of the features of the M.3 that had been retained in the Australian design. The only drawing of the M.3 gear box then in the possession of the directorate presented little more than a pictorial record of the assembly. Despite

[8] Arguments concerning the use of Cadillac engines extended beyond the technical to the political sphere. The Federal Opposition (Labour) suspected connivance with General Motors, and when it came into power in 1941 a committee was set up to investigate the matter. These investigations showed the committee that there were no grounds for this suspicion—that the Cadillac had been selected by unbiased experts, mainly Watson and army engineers, and was the only available engine with the necessary horse-power.

[9] A. R. Code. Engineer; with Vacuum Oil Co till 1941; Dir of AFV Producn 1941-44; Brit Min of Supply in AFV Directorate 1944-46. B. Melbourne 1901. Died 11 Sep 1947.

every effort, Chamberlain failed to obtain anything more informative from the United States. In desperation the Munitions Department asked the army to send a personal representative with full military credentials. With this backing Lieut-Colonel Milner[1] was immediately successful. The directorate's forebodings about the difficulty of making synchromesh gears proved justified. The detailed drawings only served to confirm its fears. In the meantime the Munitions Department had interested Mr Coote[2] in designing a "crash" gear box which did not require a complicated synchronising mechanism and which was within the capacity of Australian industry to manufacture quickly. These were typical of the problems facing Australian engineers in the early days of the tank project, which were, in consequence, a period of considerable confusion. For some time little real progress was made.

In the hope of avoiding obstacles which might hinder the implementation of the design of the Australian Cruiser Tank, the Ordnance Production Directorate began to favour a design for a much lighter tank known as the A.C.2, proposed by Chamberlain soon after his return from the United States in May 1941. Had this design been adopted it would have been almost completely dependent on imported parts, which was perhaps the main argument in its favour. The A.C.2 was, however, acceptable neither to the A.F.V. Division nor to the General Staff, which was firmly convinced that it was too light to meet their requirements. In this opinion they had the backing of senior members of the A.F.V. Division. It was often said by uninformed critics during this period of confusion that the army did not know what kind of tank it wanted. The army did, however, know perfectly well what it wanted, and said so, in no uncertain terms.

Towards the middle of 1941 the whole project was bogged down and matters had reached such a pass owing to the widely divergent opinions about design and manufacture that it was plain some resolute action must be taken. The Prime Minister, Mr Menzies, called together the chief personalities concerned on 15th July 1941 and in effect told the experts among them to stop arguing and build some tanks. This situation was not peculiar to Australia. Churchill, in his memoirs, quotes a similar experience in Britain.

Shortly after this meeting Menzies announced over the radio the formation of a separate Directorate of Armoured Fighting Vehicles with headquarters at Fishermen's Bend, Victoria.[3] Code, who was appointed director of the new organisation, was not new to the tank project since as Controller of the Armoured Fighting Vehicles Section in the Ordnance Production Directorate, and as Chairman of the Automotive Advisory

[1] Col A. Milner. Supt of Design AHQ 1941-42; ADOS 5 Div 1942-43; DDME III Corps 1943-44, MGO Branch LHQ 1944-45. Regular soldier; of Canterbury, Vic; b. Burnley, Eng, 5 Apr 1908.

[2] E. R. Coote. Managing Director Coote and Jorgensen Ltd. Engineer; of Sydney; b. Sydney. Died 24 Apr 1949.

[3] On 11 Jul 1941 Lewis wrote to General Northcott, then Deputy Chief of the General Staff and, in September, to become commander of the 1st Armoured Division:
(i) There will be set up a separate organisation on Armoured Fighting Vehicles which organisation will be in the Ministry of Munitions. [Later, owing to strong pressure from certain quarters, this decision was revoked and it was arranged that there should be an Armoured Fighting Vehicles Division within the Ordnance Production Directorate. Hartnett was dis-

Panel, he had already taken an active part in the exploratory work on the tank between June 1940 and June 1941. Mr Bromley[4] was appointed Controller and Production Manager.[5]

Although Menzies had taken what seems in retrospect to have been the only reasonable way out of the difficulties surrounding the tank program, his action was the subject of criticism, most of which came from disappointed members of the Ordnance Production Directorate and of the Army Directorate of Design. Neither organisation wholly approved of the separate Directorate of Armoured Fighting Vehicles. Some members of the Master-General of the Ordnance Branch were highly critical of what they alleged to be the army's loss of the right to design the tank.

In the production of most munitions, commercial manufacturers, once they were supplied with the necessary high-precision machine tools, experienced little technical difficulty since the requirements were clearly laid down in British specifications. Furthermore, the Government helped them out by lending them teams of experts from its own munitions factories. With tanks, on the other hand, there was no such background of experience or of equipment of the specialised type needed for their manufacture.

Another difficulty that faced tank manufacturers was that of making the most effective use of civilians with first-class experience in design and production engineering. The existence of the directorate made it easier to recruit highly-specialised engineers who were not willing to serve as non-commissioned or relatively junior officers in the army. It did, in fact, bring together in one organisation the best civilian engineers and scientists and top-ranking army experts concerned with the design of tanks.

Australian industry at the beginning of the war was reasonably well supplied with engineers experienced in the design of mechanical equip-

satisfied with this arrangement and Armoured Fighting Vehicles became a separate directorate once more on 9 Apr 1942.]

(ii) The head of the organisation shall be in charge of the production of armoured fighting vehicles.

(iii) The army will issue the General Staff specifications.

(iv) There will be one Design Section embracing both basic and detail design.

(v) The head of the organisation will at the outset take with him from the Ordnance Production Directorate all the men he may require from this directorate who have been engaged on armoured fighting vehicles.

(vi) The personnel of the Design Section should consist of the present Military Design Section (A.F.V.) and the production draughtsmen reinforced and other personnel as necessary. This section will be a joint Military Civil Section. The military personnel will be seconded to the Armoured Fighting Vehicles project.

(vii) The head of the Design Section will be Col Watson.

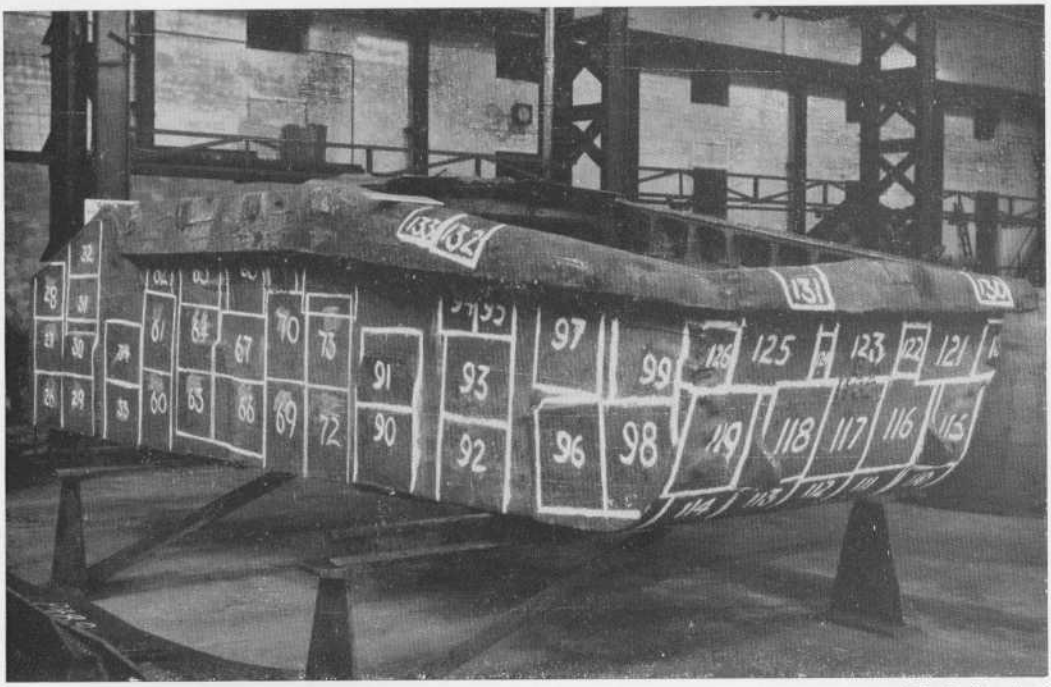
(viii) The Design Section will be part of the Armoured Fighting Vehicles Section under the head of that establishment.

(ix) Both the head of Armoured Fighting Vehicles [Mr Code] and Col Watson will have the right of direct access to the Chief of General Staff.

(x) There will be a branch of the Inspection Dept whose activities will be confined to armoured fighting vehicles. The Officer in Charge of this section [Col R. Smith], who will be known as the Chief Inspector of Armoured Fighting Vehicles, will have direct contact with the Inspector-General of Munitions. He will be concerned only with armoured fighting vehicles and will maintain the closest contact with the head of Armoured Fighting Vehicles.

[4] H. J. Bromley. Production Manager Clyde Engineering 1939-40, NSW Board of Area Management 1940-45, Siddons Drop Forging Ltd 1945-49, and of Coote and Jorgensen 1949-53. Of Melbourne; b. Fremantle, WA, 28 Jun 1906. Died 20 Sep 1954.

[5] The principal officers of the AFV Directorate were: A. R. Code, Director of AFV Producn; Col W. D. Watson, Chief of Design; M. S. Walker, Drawing Office Supt; R. Perrier, Automotive Design Engr; A. P. Taebring, Research and Developt; Col R. F. Smith, Chief Inspector, AFV; Maj L. H. Vernon, Liaison Officer for the Director of AFV.



(*H. J. Bromley*)

Hull of the Australian Cruiser Tank from the rear port side.



Testing the Australian Cruiser Tank.



(Dept of the Army)

Three sub-machine-guns: Owen, at top; Thompson, centre; Austen, bottom.



(Australian War Memorial)

Men of the 2/16th Australian Infantry Battalion watching Allied aircraft bombard The Pimple before the successful attack on Shaggy Ridge (27th December 1943). An Owen gun can be clearly seen in the left foreground.

ment produced by "jobbing" methods; but mass-production methods had not been developed in Australia to the extent that they were in the United Kingdom and in the United States, for example. By the time the Armoured Fighting Vehicles Directorate was established most of the relatively few Australian design and production engineers had been taken into such projects as aircraft production.

Notwithstanding these difficulties, under Watson's guidance the design of the Australian Cruiser Tank Mark I began to take shape towards the end of 1941. Watson was a strong believer in close cooperation with the firms selected to carry out the manufacture of tank components during the design period, and as a result of his specialised knowledge of tank requirements, and thanks also to the ingenuity of Australian industry, the A.C.1 design incorporated a number of interesting and novel technical solutions to the general problem of blending the ideal of army requirements with the hard realities of industrial capacity. The design which finally emerged incorporated such modifications to the M.3 as

(*a*) a simple crash type gear box (instead of synchromesh),
(*b*) modified driving axle casing and details,
(*c*) simplified track design to reduce machining,
(*d*) Hotchkiss type suspension,
(*e*) one-piece cast hull, eliminating many machined surfaces,
(*f*) low silhouette,
(*g*) the use of Cadillac engines.

The design evolved by Watson was described as a blend of British ideas on armour silhouette and shape with American automotive practice.

If the intention was to use the Australian Cruiser Tank alongside British and American tanks, the more closely it conformed to standard designs the more readily it could be serviced and repaired. Opponents of the tank project have criticised the A.C.1 tank on the score that it did not conform closely with British and American designs, but it should be remembered that departures from a standard design were forced upon Australian engineers by the limitations of Australian industry.

Once it had been decided to cast the armour plate, a small-scale model of A.C.1 was built and exhibited at a meeting of steel and foundry experts held in Melbourne. They were asked if the necessary castings could be made in Australia. From the resulting discussion it was decided that the firm of Bradford Kendall Ltd of Sydney, leading steel founders, should undertake casting the main components, including the hull.

The bullet-proof steel developed by Mr Bishop of the Broken Hill Proprietary Company Ltd, which had been so successfully used in Bren-gun carriers and other armoured fighting vehicles, was not well suited to making tanks by the casting process. In order to render the steel castable, but at the same time to retain its desirable ballistic qualities, Bishop, working closely with Bradford Kendall, decided to try the effect of lowering the percentage of chromium, raising that of manganese and silicon, and leaving the percentage of zirconium about the same as that in bullet-proof steel.

Zirconium, which had been added because of its capacity to enhance toughness by removing excess oxygen and hydrogen (both of which had an embrittling effect), and to render excess nitrogen more or less innocuous by forming a nitride, also improved the fluidity of the molten steel, thus facilitating casting.

On account of the failure of earlier token plates under firing tests, the first specification for the modified bullet-proof steel was amended slightly. Microscopic examination revealed that when the zirconium content exceeded about 0.12 per cent, the zirconium nitride which was formed crystallised into clearly defined cubes. In the belief that the sharp corners of these cubes were liable to initiate cracks under severe shock, it was decided to reduce the zirconium content from a maximum of 0.25 per cent to 0.10 per cent. This adjustment in formula was found to alter the crystal habit of zirconium nitride from cubes to needles, which were by comparison harmless. Whether this change in crystal habit was the significant factor influencing the physical properties of the steel was not certain; the important point was that the steel did become a good deal tougher. Tests made between October 1942 and January 1943 showed that with an average zirconium content of 0.20 per cent, ballistic requirements were exceeded by 90 feet per second; that is, the plate failed only when the projectile's velocity was 90 feet per second greater than that stipulated in the specification. When, however, the zirconium was reduced to an average of only 0.05 per cent, the velocity in reserve rose to 165 feet per second.

As first planned, the hull was to be cast in six parts which were subsequently to be bolted together. When completed it would be 17 feet 7½ inches long, 6 feet 8½ inches wide, and 4 feet 5 inches deep, and would weigh approximately 8 tons. Moreover, it would have to be done with a steel whose castability in these circumstances was quite unknown. The idea of casting the armour for a tank was not new: it had been tried in France, though for a very much smaller tank. As far as can be ascertained no other country had tried to cast armour plates for a tank of the size of the A.C.1.

After some preliminary trials carried out under the enthusiastic leadership of James Kendall,[6] skilled foundry men of Bradford Kendall Ltd decided that they could probably cast the hull in one piece, and late in 1941 they were successful. The casting of this large and complex unit was eloquent testimony to the skill of the tradesmen of the foundry industry.[7] Other, less difficult armour castings such as those of the turret, front axle housing, gun mantles, turret front plate and final drive cover, were made by the same firm.

The difficulties of fabricating the armour were not, however, over with successful casting. The castings had to be subjected to heat treatment in

[6] E. James Kendall. (Served AN&MEF 1914-15.) Managing Director, Bradford Kendall Ltd. Of Sydney; b. Nova Scotia, 13 Dec 1890. Died 5 May 1943.

[7] It is a matter of interest to record that about 10 years later it was reported from the United States (in the *Sydney Morning Herald* of 2 Jul 1952) that a tank, the Patton 48, embodying a one-piece hull casting, was adopted by the United States Army.

order to produce the desired physical characteristics in the armour; finally many areas of the hull had to be machined to close tolerances. Heat treatment, comprising such operations as annealing, tempering and hardening, was a normal and universally adopted practice in steel making, but no firm in Australia had ever before attempted to heat-treat an article of the size of the hull. The difficulty of the operation lay in maintaining closely controlled temperatures throughout a large volume of space for long periods of time. Coal gas appeared to be the only fuel suitable for achieving this objective.

The task of designing and building these furnaces was undertaken by the Australian Gas Light Company of Mortlake, New South Wales.[8] In all, seven furnaces were built, each measuring 9 by 21 by 6 feet. Firing was so arranged that the temperature throughout each furnace, even in those operated at high temperatures, was uniform to within about five degrees. It was, moreover, possible to hold the temperature as low as 175 degrees centigrade for many hours if necessary. The whole cycle of treatment could be carried out by moving the hull into successive furnaces down a line.[9]

During August 1942 army inspectors found that a number of castings selected for test under gun fire proved not quite capable of meeting requirements, despite the fact that the static physical tests laid down were fully complied with. Examination of the castings under the microscope failed to reveal the cause and it was thereupon assumed that the particular steel chosen was capable, in the case of occasional heats, of exhibiting what was known as temper brittleness. This characteristic was revealed only when a test piece, particularly one with sharp corners and re-entrant angles, was subjected to shock. Though the cause of the phenomenon was unknown, the remedy was simple and consisted of quenching the steel in water after it had been tempered. When double tempering treatment was given, one quenching sufficed. In these circumstances the steel rarely, if ever, failed.

Satisfactory as it was to know that Australia had produced cast armour for her tanks which fulfilled all tests specified, it seemed desirable to discover how it compared with the oversea product; a few turrets were

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[8] The work was done by Messrs Banks, Peterson and Corbett of that company.

[9] The heat treatment cycle was as follows:

1. Anneal.
   Raise to temperature (1050-1100 degrees C.) in 7 hours hold at temperature 3 to 4 hours, cool out in furnace for 24 hours, temperature distribution in furnace to be within plus or minus 20 degrees C.
2. Normalise.
   Raise to 900 degrees C in approx 9 hrs, hold at temperature 3 hours, cool in air. Temperature distribution in furnace to be within plus or minus 20 degrees C.
3. 1st tempering (forced convection heating).
   Raise to 650 degrees C in 3 hrs, hold at temperature from 7 to 9 hours. Temperature distribution in furnace to be within plus or minus 20 degrees C.
4. Hardening.
   Raise to 850 degrees C in 9 hrs, hold for 3 hrs then quench in water. Temperature distribution in furnace to be within plus or minus 20 degrees C.
5. 2nd tempering (forced convection heating).
   Raise to 600 degrees C in 3 hrs, soak for 9 hrs, cool in air. Temperature distribution in furnace to be within plus or minus 12 degrees C.
6. Stress relief if necessary. Heat to 550 degrees C in 3 hrs, hold for 3 hrs.

therefore taken from imported tanks and tested under gun fire. The results obtained demonstrated that the armour on the Australian tank was in no way inferior to the imported article. If anything, it showed slight superiority. The main factors contributing to this happy position were the soundness of the foundry technique, and the efficiency of the steel-making and heat-treatment processes.

The considerable amount of scientific investigation and testing at all stages of this developmental work on the tank armour was carried out by a team of metallurgists drawn from private and government laboratories. Mr Clark of the B.H.P., Chief Metallurgical Adviser to the Director-General of Munitions, took a leading part in supervising work on the heat treatment of the armour plate; investigation of technical problems of casting was carried out by Mr Cerutty[1] of the staff of the Sydney Technical College. Much of this work was done in the laboratories of the Technical College, which at that time were fairly well equipped for simple metallographical studies. For all physical testing of the cast armour plate (except ballistic tests) Mr Bennett,[2] Senior Metallurgist in the New South Wales Government Railways, was responsible. These tests were made chiefly in the Railway Workshops at Redfern.

Systematic study of every phase of the production of castings and of the quality of the castings themselves was undertaken by the Munitions Supply Laboratories in their branch at Villawood, New South Wales. As a means of perfecting casting technique and ensuring flawless armour plate, radiological tests (using radium as a source of penetrating γ-radiation) were made on the solidifying, feeding and running of the castings. The metallurgical section at Villawood also maintained facilities for the magnetic and ultrasonic method of detecting fine cracks in castings.

While all this work on the armour of the tank was in progress problems relating to the power unit were receiving attention. Adhering to the design of Code and Burstall, General Motors-Holden's succeeded in mounting 1940 model Cadillac engines in "clover leaf" formation (two engines side by side in front and one engine centrally at rear). Each engine was connected by shafts to a transfer gear-case and from this gear-case a single shaft transmitted the full power of the three engines forward to the main gear box and thence to the final front sprocket drive. The transfer gear-case served also as a means for taking off power for the 40-volt generator operating the turret driver's motor and trailer and for the compressor which supplied air to the servo-controlled steering and braking mechanism.

A distinctive feature of the A.C.1 was its low, streamlined silhouette: it was about three feet lower than the M.3, and in this respect was well in advance of oversea design. Watson regarded this feature as most important from the point of view of practical warfare, not only in its effect in turning direct hits into glancing blows, but also in enabling the tank to push its nose over a hill and fire at the enemy without exposing too

[1] H. S. Cerutty. Metallurgical consultant; of Sydney; b. Melbourne, 12 Jun 1895.

[2] R. H. Bennett. Assistant engineer NSW Government Railways 1928-46, chief metallurgist since 1946. Of Sydney; b. Sydney, 22 Feb 1906.

much of its area to enemy gun fire. Oversea tanks were mainly built up from rolled armour plate of rectangular plane sections. In such a form of construction it was difficult to obtain a low, streamlined silhouette; the casting technique, on the other hand, made it easier to achieve this. The turret drive mechanism was novel, and although responsible for much anxiety in the early stages of the tank trials it was eventually developed into quite a satisfactory unit by Captain Harris.[3]

Early in the process of developing the detailed design of the tank a full-sized wooden "mock-up" was built to exact dimensions, this being much more rapidly accomplished than a model in steel. Watson used to bring in all who were likely to have anything to do with the tank, including officers from the armoured division, to discuss many of the more minute details of design, using the wooden mock-up as a basis for discussion and demonstration. As soon as he had satisfied himself as fully as possible on the questions of space and dimensions, he gave the signal for the construction of working pilot models in steel.

Details of these models were as follows: weight, 28 tons; length, 21 feet; width, 9 feet; height, 8 feet 5 inches; main armament, 2-pounder gun in turret with one Vickers .303 machine gun mounted coaxially and a second mounted centrally in front of the hull; a Bren gun with anti-aircraft mounting and a sub-machine gun completed the armament. The tank was designed to attain a top speed of 35 miles an hour and in this weight class it would be the fastest tank in the world. Its gear box gave five forward speeds and one reverse. Its range, when equipped with a jettison tank, was 200 miles. The tracks were adaptable to the use of rubber or steel track links. All later A.C.1 tanks were equipped with rubber-treaded steel links imported from the United States. The body of the tank was carried on Hotchkiss bogie suspensions, three on each side of the hull. The steering ratio (length of track on ground to distance between track centres) approximated to the optimum figure and in consequence steering and general manoeuvrability were especially favourable. The hull armour was 65 millimetres thick in front, 45 millimetres at the side and 25 millimetres on top; that of the turret was 65 millimetres thick.

Internally the tank was roughly divided into three compartments: front, middle and rear. The front compartment accommodated the driver and forward gunner, individual seats being provided. The driver's compartment containing the various controls was on the right; the forward gunner's seat was on the left beside the Vickers machine-gun. The turret and turret-basket occupied the centre of the tank, which also housed the ammunition for the 2-pounder gun. In the rear compartment were housed the engine, radiators, cooling fan and fuel tanks. The other three members of the crew—commander, 2-pounder gunner and wireless operator—occupied the fighting basket.

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[3] Capt L. A. C. Harris, BE. Design and Tech Offr, CMA Branch AHQ, 1941-42; DAFV 1942-43; EME Design Div, MGO Branch, 1943-45. Electrical engineer; of Charlton, Vic; b. Melbourne, 31 Jan 1915.

Three models were constructed: one for automotive tests, the second for gunnery tests and the third as a prototype for mass production. The first automotive pilot model was delivered in January 1942 by the New South Wales Railways and was tested at the tank range at Puckapunyal on 15th February 1942. Automotively the pilot model performed remarkably well, and attained a speed of 40 miles per hour. Before this the army had carried out many preliminary tests at Fishermen's Bend and Torquay, Victoria. The second pilot model was delivered for gunnery trials on 5th April 1942 and the third on 3rd June.

Early in 1942 when a Japanese invasion seemed imminent the Directorate of Armoured Fighting Vehicles arranged for components of the tank to be put into mass production as drawings were progressively released, without waiting for pilot models to be completed and tested. A survey of industry having revealed that Sydney possessed the greatest potential for tank production, Sir Philip Goldfinch, Chairman of the New South Wales Board of Area Management, promptly took up the challenge and organised staff to implement the plans for industrial development outlined by the Department of Munitions.

This arrangement, by which the designers were in one State and the manufacturers in another, added a further complication to the tank project. It is difficult to see how it could have been avoided, since very close liaison between the Directorate of Armoured Fighting Vehicles, the General Staff, and the Master-General of Ordnance was essential at all stages of the program. Location of the design staff in Sydney would have severely handicapped progress and army approval of designs. On the other hand, when there was great pressure to release for production components that had not yet been tried out in pilot models of the tank, many advantages would have accrued if the design staff had been closer to the manufacturers. The authorities originally responsible for the decision to make tanks probably did not foresee all these complications.

The section of the New South Wales Board of Area Management specially created to supervise the manufacture of tanks was responsible for a new departure from general practice when it undertook to act as major coordinating contractor for the tank project. Until then the common practice had been for the Board of Area Management in each State to appoint a private firm as major coordinating contractor, to be responsible for placing orders on hundreds of other firms for mass production of individual components, and also for production planning, scheduling and follow-up work. This procedure worked smoothly for smaller projects where complete designs were available, but when production was begun on a major project before designs were finalised, as with the tank, there was a risk of undue delay. In its capacity as major coordinating contractor, the Board of Area Management was able to avoid much delay by placing, at the outset, a bulk order for materials likely to be used in the construction of the tank. Orders were even placed before it was known which contractors would make the different components. If bulk orders

for materials had not been so placed the A.C.1 would probably never have been produced.

Had there been any private firm experienced in the production of tanks, the ideal arrangement would of course have been to use it as the major coordinating contractor, but few Australian firms possessed organisations even remotely adequate for tank production. In fact the various State railway departments were the nearest approach to what was required. The Victorian Railways, however, had been appointed major coordinating contractors for the production of Bren-gun carriers. At the time the New South Wales Railways were asked to act as major coordinating contractors for the tank project they had already been committed to participation in the manufacture of the Beaufort Bomber and could not undertake responsibility for any phase of the work other than the final assembly of the tank.

Major contractors selected for the manufacture of tanks in New South Wales were:[4]

(*a*) Armour castings, including the hull, turret, front axle housing, entry and exit doors, etc: Bradford Kendall Ltd.
(*b*) Gear box: Sonnerdale Ltd.
(*c*) Driving axle assembly and transfer box: Coote and Jorgensen Ltd.
(*d*) Power unit: General Motors-Holden's Ltd.
(*e*) Suspension: Tullochs Ltd.
(*f*) Radiator assembly: Harris Hutchinson Pty Ltd.
(*g*) Steel castings other than armour castings: Hadfields Ltd and Industrial Steels, Ltd.
(*h*) Turret drive mechanism: Electric Control and Engineering Ltd.
(*i*) Final assembly of all tanks from components to be supplied by the Ministry of Munitions: N.S.W. Government Railways.

In addition there were 312 minor direct contractors with the Board of Area Management and 259 sub-contractors.

As it would have been impossible to make the tanks in the numbers required with the engineering facilities then existing in New South Wales, the program provided for the construction of six major workshops (annexes) as follows:

Bradford Kendall Ltd. . . .	est cost	£249,000
Coote and Jorgensen Ltd . .	„ „	£113,000
Sonnerdale Ltd	„ „	£98,000
Hadfields, Ltd	„ „	£45,000
Industrial Steels Ltd . . .	„ „	£28,000
N.S.W. Govt Railways . . .	„ „	£108,000

The annexe at Bradford Kendall's at Alexandria, New South Wales, which was built on a site previously occupied by a "tin hare" dog-racing course, was designed and equipped expressly to produce the hull,[5] turret, front axle housing, front turret plate, gun mantles and final drive cover. Equipped with a modern sand-handling equipment, moulding machines and

[4] Victorian contractors were selected later when the intention was to double the rate of production. The tank program was terminated about the time the extra capacity in Victoria was completed. Ruwolts were to have made the armour plate casting and the Steel Co of Aust castings other than armour plate.

[5] The first three hulls were cast in their old foundry.

special-purpose milling machines, it became the most modern steel foundry in the Commonwealth. One of the reasons for casting the hull in one piece was the belief that much labour and expense would be saved by eliminating the drilling, welding and riveting (or bolting) that would have been necessary had it been fabricated from five separate components. In point of fact this economy was not fully achieved, owing to the long time it took to mould a hull by hand. A moulding machine had been ordered from the United States about the time of Pearl Harbour; by the time it had been built and shipping space had been found for it, the hand method was so well established that the question arose whether production should be interrupted to allow the installation of the new machine. Since an output of six hulls a week did not warrant any change, the new machine was not installed.

A one-piece hull possessed certain advantages apart from the saving of machines and manpower; it provided greater rigidity and obviated the necessity for close-fitting joints. It was also less vulnerable—lead from a striking bullet would "splash" through even the best joint if a direct hit was made.

On being furnished with the requisite machine tools, many of which were obtained from the United States under the Lend-Lease Agreement, the annexe at Sonnerdales in Sydney went into production of the largest gear box made in this country during the war, at the rate of ten a week. The manager of this annexe, Mr Jones,[6] was sent to the United States to study the latest methods of producing gears and to select machine tools for use in Australia.

Tooling of the annexe at Coote and Jorgensen's for the driving assembly was not completed until about August 1943, which meant that the firm had to manufacture its own tooling.

Late in 1941 Messrs H. W. Muter and G. J. Blattman (assistant engineers in the New South Wales Department of Railways) were sent to the United States to study techniques used in the assembly of tanks. In the light of their experience of the most modern practices in the largest tank factories in the United States, they helped to design the final assembly shop at Chullora, which was completed by July 1942. In this shop all the tank components, numbering more than 2,000, were brought together from some forty-seven different contractors.

The target originally aimed at was five tanks per week by May 1942. Output fell short of the target owing to the difficulty of finalising designs and making working drawings available to manufacturers. The tank program was also in serious competition with other munitions programs for manpower. However, by the use of a large staff of follow-up liaison officers, Mr Munro,[7] Supervising Engineer for Production on the staff of the Board

[6] C. E. Jones. Works Manager Sonnerdale Ltd to 1941; Manager Tank Transmission Annexe 1941-50. Of Sydney; b. Charters Towers, Qld, 22 Aug 1900.

[7] C. H. Munro, BE. Lecturer in charge Engineering, Sydney Technical College, 1936-41; Supervising Engineer (NSW) AFV Division and Controller of Production Small Craft Construction Division 1941-45; Major RE, Brit Army in Burma, 1945-46. Professor of Civil Engineering, NSW Univ of Technology; b. Toowoomba, Qld, 23 Mar 1904.

of Area Management of New South Wales, was able to reduce to a minimum the time between the release of drawings for production and delivery of the required item to the assembly line. Pending the completion of tooling, design and construction, jobbing methods were used to start the production line.

In August 1942, after many delays, the first Australian Cruiser Tank left the assembly line. By the end of October sixteen more had completed the test run. Comprising 50 miles of road and 25 miles over a course involving sixteen circuits of cruising ditches, creeks and embankments, the course, in the opinion of Watson, was as severe as those in Britain. Twenty-two months before it made this test run, the A.C.1 existed only as a General Staff user specification.

Once the complaints of the production engineers against the design staff, because of continual minor changes in design and delay in releasing production drawings, had died down, industry might reasonably have expected to settle down to steady production with a goal of five tanks a week. But this was not to be. The rapidly changing scene on the war front and the development of improved tanks (particularly by the enemy) pointed to the necessity for major changes to match this progress. It was therefore decided to limit production of the Mark I tank to sixty-six in all and to incorporate several improvements in a second mark. The main weakness of the A.C.1 when compared with the latest oversea designs was its poor fire power.[8] The means of improving this were limited to weapons made in Australia. Therefore the A.C.1 was fitted, for test purposes, with a 25-pounder gun in a redesigned turret. Firing trials exceeded the expectations of designers and of army observers. An eye-witness account of the test, which was made at the old Fort Gellibrand at Williamstown (Victoria) on 29th June 1942, states:

> As there was no previous experience in firing so powerful a gun from a turret, and our tank was a newly designed tank and had not been tested for firing anything more than the customary anti-tank 2-pounder gun, practically a toy alongside the 25-pounder, safety precautions were taken on first firing; a lanyard of some 80 feet was attached to the firing trigger in the turret and the gun crew and visitors were ordered behind the rebutments of the fort. There was difficulty, however, in obtaining a straight pull on the lanyard and after several efforts the firing officer went into the turret and disregarding all the unknown factors and dangers released the firing trigger with his hand and thus proved the gun and turret to be completely coordinated and successful. We all saw this being done and several more shots were fired before we left.[9]

This was the first time, as far as is known, that so powerful a gun had been thus mounted and fired in an Allied tank. The redesigned tank was known as the A.C.3. In general form it was similar to the Mark I, but the turret was of necessity slightly larger and the hull angles were modified to give improved protection. To accommodate the larger gun the

[8] Other weaknesses were that the bogie wheel tyres wore out too quickly; the turret drive gear did not operate satisfactorily with the tank on an incline of 25 degrees or over; its engine cooling was not entirely satisfactory.

[9] Jensen's personal recollections.

coaxial Vickers machine-gun in the turret was eliminated and the one in the front of the hull was removed, together with the gunner's accommodation, to make way for storage of the larger ammunition. The turret had a full 360-degree traverse and was operated either manually or electrically. Thus, instead of having more or less to aim the tank itself at the enemy, as was the case with the American M.3 Medium Tank, the A.C.3 (and A.C.1), even if brought to a standstill, could fire in all directions. The tank now had a crew of four: commander, driver, gunner and radio operator.

The prototype, complete with all its guns, was tested at Wakefield, South Australia, in February 1943 and by April a final decision was made to mount this gun on a production basis. Observers from the American Army are said to have been favourably impressed by the A.C.3. The following paragraph appeared in the *Washington Post* of 30th July 1942, under the heading "Australian Tanks Held Better Than Nazis' Or Ours":

> United States officers today declared that tanks built in New South Wales, Australia, were superior to tanks of corresponding weight and armament used by the United States, British and German Armies. The tanks were designed by Colonel Watson of the British Army, an expert on tank design loaned to Australia by the British War Office 18 months ago. . . .

Commenting on this article Sir John Jensen said: "We did not know the source from which this information was derived and did not inquire, and we did not know whether in fact American officers had said what was attributed to them, but certainly some of us believed the statements to be well founded."

A better-authenticated assessment of the tank program was made by Colonel Green[1] of the United States Army who visited Australia under the auspices of Lend-Lease and prepared a report on all three marks of the cruiser tank. While not favourably disposed to the idea of a really large-scale manufacture of tanks in Australia, and highly critical of some features of the tank—such as the lack of synchromesh gears and the use of bronze bushings instead of roller bearings—he did make some favourable comments:

> Considerable ingenuity has been displayed throughout all design phases. . . . Development of cast armour represents a real contribution. Gun mounting is excellent—this provides maximum fighting compartment space utilisation.

In June 1943 Munro reported to the Board of Area Management that fifty-eight A.C.1 tanks had been assembled and had satisfactorily completed the test course, but that production of the A.C.1 had been deliberately slowed down awaiting the detailed production drawings for the A.C.3. Further pilot models of the A.C.3 were being assembled.

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[1] Col G. A. Green, MC. (Capt in Royal Tank Corps 1917-18.) Consulting Engineer to U.S. Sec of War 1940-41; Lend-Lease Administrator in London; Asst Dir of Industry on Marshal Plan, Paris, 1948-49. B. Sydney 8 Jul 1882. Died 21 Feb 1949. Green was educated in Australia. Before the first world war he went to England where he became superintendent of design and construction in the London General Omnibus Co. and later to America where he became general manager of the Fifth Avenue Coach Co. In the first world war he became Deputy Chief Mechanical Engineer of the Tank Corps. After that war he held senior posts in General Motors and other companies.

A novel feature of the A.C.3 was the design of the power unit, for which Monsieur R. Perrier, who had joined the directorate's staff from Japan, was largely responsible. With the introduction of the larger gun and ammunition of Mark III, greater economy of space within the tank, and increased power, were essential. The "Perrier-Cadillac" power unit, in which the engines were mounted radially in a single row on a common triangular, fabricated steel case, was designed to satisfy both requirements.

Mark III was not the last of the pilot models of the Australian Cruiser Tank to be built. Yet another, Mark IV, an experimental model, was built incorporating several major changes, including the installation of the high-velocity 17-pounder gun which had just been manufactured by the Department of Munitions. Mark IV was a much heavier tank than its predecessors. The nearest approach to a wholly Australian-made tank, its mass of 32 tons was moved by a power plant consisting of four Gipsy Major engines built by General Motors-Holden's.

As late as March 1943 the army was still asking for tanks. In a memorandum to Lewis the Chief of the General Staff stated that the army requirements of tanks were:

A.C.1 (2-pdr) . .	65
A.C.3 (25-pdr) .	200
A.C.4 (17-pdr) .	400
A.C.4 (25-pdr) .	111

But in fact the Mark III Australian Cruiser Tank was never produced in quantity; before it reached that stage, Lend-Lease authorities in the United States had begun to query the wisdom of Australia's continuing with the tank program, holding the view that it would be better for her to concentrate on building more railway locomotives and waggons instead of importing them from the United States. Furthermore they believed that men and materials being taken up by the tank program could be better used in servicing the 600 American tanks then in or about to arrive in Australia. For this reason they temporarily held up all new requisitions for the Australian tank program. A spirited defence of the Munitions Department's policy and a fresh endorsement of this policy by General MacArthur caused the Lend-Lease authorities to modify their attitude slightly, but by the middle of 1943 the writing was on the wall. There being no further need for Australian tanks and every reason for diverting the manpower employed on the project to more valuable purposes, the War Cabinet ordered cessation of their production, in July 1943.

The strenuous efforts of Australian industry (at least 2,000 men were employed directly in making tanks—and possibly double that number were employed indirectly), with the expenditure of more than £4,000,000, provided yet another example of the frustration of a people's best endeavour, which is so typical of war. Of the 66 Mark I tanks delivered to the army, none was ever used in operations against the enemy.

It has been said that the Australian Cruiser Tank was obsolete by the time it was produced. This is only partly true. The army, acting on the

views prevailing at the time, had asked for a 2-pounder gun but during the time it took to produce the tank, oversea designs, especially in regard to the armament of the tank, had made great advances. A 2-pounder gun was no longer adequate. This kind of thing happened to a great many munition projects and it was a result to some extent of the inevitable time lag between design and large-scale production, and to some extent of the changing strategical situation.

The reason why Australian tanks were never used in operations was that by the time they came off the assembly line mastery of the sea lanes of the Pacific had been won, and American (General Grant) tanks were arriving in Australia in sufficient numbers to equip three divisions of the Australian Military Forces. One division had already been equipped with them before the A.C.1 came into production.

The technical assessment of the Australian Cruiser Tank by engineers may create an unduly favourable impression of its merits as a weapon of war. Since the tank was never put to the real test—namely use in action—one can do no more than guess what its military usefulness might have been. Some military authorities remained sceptical about its fighting qualities long after the war. On the other hand it must be pointed out that the army saw fit to use the Australian Cruiser Tank, under the name of the Sentinel, for training, and it was not declared obsolete for this purpose until early in 1956.

This is not to say that the tank project was not open to criticism. Probably one of the most serious grounds for criticism is the fact that it was carried on for so long after the need for tanks had disappeared. The obvious time to discontinue production was in late 1942 when the armoured divisions were fully equipped with American tanks. Early in 1943, when it became apparent that a Japanese invasion with consequent armoured warfare in open country was no longer likely, the army began to disband its armoured divisions. It would have been wise to cease tank production about nine months earlier than the time eventually decided on. The very success of the tank program in its later phases, especially that which attended the mounting of heavy guns ahead of most Allied countries, no doubt had its share in tempting the authorities to hold on after the real need had disappeared.

As far as its actual military use was concerned, the machine-gun carrier was far more important, though technically its manufacture was much less interesting than that of the Australian tank. Production, delegated to four main concerns (Victorian Railways' Newport Workshops, South Australian Railways' Islington Workshops, Metropolitan Gas Company's Fitzroy Workshops, Victoria, and the Ford Motor Company, Homebush, New South Wales), followed the same general pattern as the tank, except, of course, that the complete design was supplied by Britain. One major alteration was made to the design: steering from a pilot stick to a wheel control. Like a tank, the carrier was powered by an imported engine (the Ford), but since the carrier was a great deal lighter than the tank, being less

heavily armoured, a much less powerful engine was required. The armour of the carrier consisted of plates of rolled Australian bullet-proof steel welded together. Successful manufacture of the carrier was achieved in all four of the above centres with complete interchangeability of all components. New South Wales firms played a big part in making spare parts, which equalled the value of the vehicles themselves.

By far the largest contributor to the program was the Victorian Railway Department, which had a long record of participation in manufacturing for defence extending back to 1900. The workshops at Newport, with the assistance of 644 sub-contracting firms, beginning in December 1940, made altogether 4,023 machine-gun carriers, and spare parts for 5,583. The Railway Workshops at Islington contributed 1,560 carriers. Many were also assembled by the Ford Motor Company. Assistance given by the Metropolitan Gas Company was especially noteworthy because it came from an industry whose previous activities were of an entirely different character. The Gas Company developed to a high pitch of efficiency the technique of welding the hull of the carrier.

Large numbers of carriers, along with appropriate spare parts, were supplied to the Australian forces in the Middle East. Owing to unsatisfactory labelling and ordering of spare parts considerable confusion resulted when the time came to use them. It was from the bitter lessons learned as a result of this experience that the Aftag plan for labelling and handling spare parts for tanks was devised. The benefits of this plan were never reaped.

The consensus was that the machine-gun carrier was the most satisfactory vehicle, as far as its operational use was concerned, produced by the Armoured Fighting Vehicles Directorate. Light and heavy armoured cars, the mortar carrier and the 2-pounder anti-tank gun carrier, together with the Australian Scout Car, were all eventually discarded as unsuitable for use by the Australian Army;[2] this, after each had been designed by an authorised representative of the General Staff, the design specification and prototype approved after exhaustive field tests, and the finished vehicles given severe acceptance tests. That a program of the magnitude undertaken by the Armoured Fighting Vehicles Directorate succeeded in producing, with the one exception of machine-gun carriers, so little equipment of use to the army, calls for some comment. In the case of the tank the time factor was all important, but there was more to it than this.

Perhaps the fundamental reason was that in the fields of manufacture represented by armoured fighting vehicles, Australia was unprepared for war. The majority of engineers and other technical men associated with the tank program within the army, munitions and industry were new to the technical problems and new to each other. Design and production of armoured fighting vehicles were not new to Colonel Watson, but Australia and her immature automotive industry were.

[2] This statement is made on the strength of opinions given in the *MGO History*.

On the other hand, manufacture of guns, rifles, ammunition and explosives was successful almost from the first months of the war because of the existence of a peacetime nucleus, small as it was, of technical experts familiar with the production of such munitions. These, together with technical experts in the government munitions factories, provided the basis from which an expansion of production was possible.

What remedies were suggested as a means of avoiding the kinds of difficulty which surrounded the A.F.V. program—difficulties that might well arise again in attempts to manufacture equipment new to Australian industry? This matter was discussed, among others, by Bromley, who proposed that after the war there should be an organisation consisting of technical men from industry who would in peace time engage actively, though in a part-time capacity, on working out plans for wartime production; and who would, in the event of war, immediately assume responsibilities in a full-time capacity within the munitions organisation. This suggested arrangement implied the fullest active collaboration in peace time between the service authorities and industry, with the idea of evolving a planned organisation that could be put into operation as soon as the need should arise.

CHAPTER 15

SMALL ARMS AND MACHINE-GUNS

IN the late thirties the Munitions Supply Board kept the Lithgow Small Arms Factory moving along making Vickers machine-guns, for which there was a keen demand, and rifles, with which Australia seemed plenteously supplied, at the rate of only a few hundreds a year. It arranged that, in an emergency, production of rifles could be pushed up to about 30,000 a year; but in the event, fewer than 3,800 were made in the first year of the war.

After the loss of equipment during the withdrawal of the British armies from Dunkirk, unprecedentedly large orders—well beyond the capacity of the Lithgow Factory to meet in any reasonable time—began to pour in from the army, which had sent a large part of Australia's reserve of rifles to Britain. The Eastern Group Conference also recommended that Australia's productive capacity should be stepped up to 100,000 rifles a year, so that she could help supply Britain and other Empire countries. For strategic reasons, and in keeping with the policy of decentralisation, factories were built at Bathurst and Orange and other country centres. At no time was the making of rifles, even though it was essentially mass production, delegated to commercial industry as was the making of artillery pieces.[1] The output of rifles rose to a maximum in 1943 and reached a total of over 400,000 for the whole war period.

Apart from the voluntary efforts of several firms in making the Owen and Austen sub-machine-guns, the one attempt to delegate the manufacture of small arms to commercial industry—namely the six-chambered revolver—proved a failure. The production directorate concerned (which consisted of business men without experience in small-arms manufacture) and the firm to whom the task was entrusted, completely underestimated the quality and the precision of the work required. This was one of the few unsuccessful efforts of wartime manufacture.

The first truly automatic machine-gun, that is one which once the trigger was pressed would go on reloading and firing itself while ammunition lasted, was invented by Hiram Maxim in 1883. Some years later the manufacturing interests of Maxim became linked with those of the armament firm of Vickers, which by applying its wide experience in the manufacture of munitions, improved the original invention and evolved a weapon known as the Vickers Machine-Gun .303 Mark I. As the technique of making machine-guns was very similar to that used for rifles, except that the tolerances for the former were more exacting, sometimes being as close as one ten-thousandth part of an inch, it was an obvious decision

[1] Commercial industry did assist in making some rifle components but never acted as major coordinating contractors. Rifle furniture (the wooden section of the weapon) was manufactured in an annexe to Slazengers Pty Ltd, Sydney, and bayonet scabbards were made by J. C. Ludowici & Son Ltd, also of Sydney.

when during the 1914-18 war consideration was first given to the proposal for the manufacture of machine-guns, that the project should be undertaken by the Small Arms Factory at Lithgow. Accordingly Mr Ford, Chief Draughtsman at the factory, visited England in 1917 and again in 1918 for the purpose of making a complete study of the manufacture of the Vickers machine-gun. The Australian-made Vickers machine-gun, produced with the aid of machine tools and gauges also of Australian origin, was successfully put through its paces in the presence of the Minister for Defence at Lithgow on 17th December 1929.

The Munition Supply Board's plans for expanding the manufacture of munitions in 1937 included the Bren machine-gun—a modern and efficient light machine-gun which was to replace the Lewis light machine-gun in British armies. It was estimated that it would take about two years and a half to establish production using Australian resources only. When war seemed imminent it was decided to hasten the project by ordering some of the manufacturing equipment from England, from contractors already engaged in supplying similar equipment to the British Government. About 1,000 machine fixtures were ordered from these contractors and the remaining equipment was reserved for manufacture in Australia, chiefly at the Small Arms Factory. Orders for cutting tools, of which many thousands were required, were placed with private industry but the gauges and some of the more intricate precision equipment were placed with the only factory where this work could be undertaken, namely the Small Arms Factory. In due course about half the machine fixtures ordered were received from England. Serious misgivings arose when it was discovered that not only were the prices charged excessive but also that the quality was below Australian standards. This led to a decision to cancel the remainder of the order and to manufacture the fixtures in Australia.

General Motors-Holden's Ltd undertook to make about 400; the rest were shared between the C.C. Engineering Co (Sydney), Telford Smith Co (Melbourne) and the Small Arms Factory. The contracts were completed quickly and satisfactorily, and although payment was made on a "cost plus" basis the charges were about 20 per cent lower than had been stated in the English quotation.

In spite of disheartening difficulties and of ill-informed criticism in Parliament, the first six Bren guns passed inspection on 13th January 1941, some six months before the planned date. Production figures for Bren guns and other small arms are shown in the accompanying table.

	Production of Small Arms and Machine-Guns						
	1940	1941	1942	1943	1944	1945	Total
Rifles .303-in .	3,480	35,040	82,098	136,262	113,460	38,310	408,650
Vickers Machine-Guns .303-in .	735	1,791	2,748	2,679	2,132	1,516	11,601
Bren Guns .303-in		186	3,081	6,848	5,290	1,930	17,335

Despite the fact that Vickers machine-guns were made at an unprecedented rate during the months when Australia was seriously menaced by

the Japanese, there were not enough to meet all requirements. In the emergency someone conceived the idea of collecting trophies from the war of 1914-18 that had been rusting in public parks for over twenty years. About 300 machine-guns so retrieved were repaired and adapted to fire .303 ammunition, and were used on beach defences and in prisoner-of-war camps. A similar attempt was made to repair old German field guns, but suitable ammunition could not be found.

Mortars, which were usually grouped with though not classified as small arms, were among the most useful weapons in the jungle. They were the heaviest weapons suitable for porterage, and consequently the heaviest weapons that could be carried into less accessible places. Quite often they were the only weapons available that relied on high-explosive effect rather than the bullet.

The mortar with which the Australian Army was equipped in 1939 was of a pattern used in the war of 1914-18; it has been described as "little more than a drain pipe". The manufacture of more effective weapons based on British designs was put in hand soon after the crisis of June 1940. With experience gained in jungle fighting further improvements were introduced—some of them based on features copied from captured Japanese weapons—which increased range and accuracy and so improved their effectiveness that the Australian Army gained a reputation for mortars similar to the one it later gained for sub-machine-guns.

All small arms and machine-guns mentioned so far were designed and developed in the United Kingdom. The practice of adopting exclusively weapons of British design and development had been pursued by the Australian Services. Britain's leadership in the design of armaments rested on her superior industrial resources and great wealth of technical experience. It was, moreover, part of defence policy to standardise weapons. A question that naturally arises is, did this policy rule out the possibility of developing and adopting outside the United Kingdom useful inventions made in other parts of the British Commonwealth? Whether an answer can be found to this question in the story of an Australian invention—the Owen gun—is debatable. If the question is limited to development, the answer is simple: the policy did not rule it out but certainly made it difficult. On the other hand the adoption of a non-standard weapon by any part of the British Commonwealth carried with it such disadvantages that only a revolutionary change in design could justify it even as a temporary measure. Yet unless it is adopted it is impossible to give the weapon its real test—on the battlefront. Because of the unusual circumstances surrounding its design, development and production, the Owen gun will be described at greater length than its military importance alone would warrant.[2]

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[2] In writing this section I have had the benefit of the comments of Brig J. W. A. O'Brien, Lt-Col J. E. M. Hall, Col E. W. Latchford and Mr V. A. Wardell.

The Owen sub-machine-gun, which received so much publicity in the early part of the war, was first brought to the notice of the army during July 1939 when its inventor Mr Evelyn Owen,[3] then 24 years old, interviewed a workshops ordnance officer at Victoria Barracks, Sydney. After the .22-inch calibre model which Owen had brought with him had been examined and ideas for its future development had been noted, Owen was told that the army was not greatly interested in the device.[4]

The weapon variously described as a sub-machine-gun (America), machine pistol (Germany) and machine carbine (Britain) was a very light machine-gun firing a pistol-type cartridge and capable of providing automatic and repetition fire. It was particularly useful in providing at short notice a relatively large volume of fire effective at a short range only; hence its great value in the close and confined conditions of the jungle. Although the Thompson sub-machine-gun, or "Tommy gun", which had been developed in the United States was fully described in the *British Text Book of Small Arms* (1929) no gun of this type had been accepted by the British Army as a regular weapon. The same was true of the Australian Army; sub-machine-guns were regarded either as unimportant or as weapons for gangsters rather than for soldiers. In fact, no army except the German had at that time conceived or accepted the sub-machine-gun as a required weapon. This, together with the fact that before 1939 it relied entirely on Britain for small arms designs, would explain the Australian Army's original lack of active interest in Owen's invention.

At the outbreak of war the only known examples of the weapon existing in Australia were a war trophy in the Small Arms School at Randwick, New South Wales—the original "Bergmann" machine pistol of the German Army of 1917—and a later development of the same weapon, the "Schmeisser", which had been seized by the Customs in Sydney from the luggage of a German passenger and was held by the New South Wales Police. Early in 1940 the Chief Instructor of the Small Arms School, Captain Latchford,[5] contrived to buy for the Defence Department an American Thompson gun from a planter in the Solomon Islands, and used it for instructional purposes. This roughly was the extent of the experience which the army was able to call on when asked to assess the value of the Owen gun. No small arms of any kind had ever been developed in Australia.

For a year after Owen had made his first approach to the army authorities nothing further was done about his invention. Despairing of making further progress with it, Owen had joined the A.I.F. and in September 1940 was on final leave before embarkation for the Middle East. In a last attempt to enlist interest he placed the working model of his gun in a sugar

[3] Pte E. E. Owen; 2/17 Bn. Motor mechanic; of Wollongong, NSW; b. Wollongong, 15 May 1915. Died 1 Apr 1949.

[4] Owen explained that this calibre was adopted only for convenience in making the model and that the gun could be readily adapted to larger calibres.

[5] Col E. W. Latchford, MBE, MC, MSM. (1916-18: 1st AIF and Dunsterforce.) Instructor, Small Arms School 1934-40, Chief Instructor 1940-45. Regular soldier; of Ascot Vale and Armadale, Vic; b. Goulburn Weir, Vic, 24 Jan 1889.

bag which he left anonymously outside the flat of Mr V. A. Wardell,[6] Manager of Lysaghts Works Pty Ltd, Port Kembla. Wardell, who discovered that the owner of the gun lived next door, quickly realised that such a gun, if it were shown to be of military value, could be rapidly produced in large quantities. He took the matter up with Mr Essington Lewis, who promptly sent Owen to see Captain Dyer,[7] Secretary of the Army Central Inventions Board in Melbourne.

The usefulness of sub-machine-guns for some kinds of military action had by now been demonstrated in the European campaigns, and Australian Army authorities were becoming a little more interested in the weapon. Dyer was much impressed with the possibilities of Owen's invention and though he was discouraged by some of his immediate superiors, who were aware that there were prospects of a similar weapon being produced in Britain in the near future, he did all he could to arrange for an early testing of the gun. Unfortunately, by now, the army's peacetime machinery for the reception and assessment of inventions had lost its efficiency owing to dilution of staffs by officers unfamiliar with the correct procedures, and also to the pressure of the large number of inventions stimulated by the war. Dyer found it expedient to approach Wardell's brother, Mr G. S. Wardell,[8] of Lysaghts, privately and unofficially in order to arrange the construction of further models of the gun. Owen obtained duty leave and within three weeks, with the collaboration of G. S. Wardell, completed a .32-inch (8.1-mm) calibre test model in January 1941; two months later a second model of .45-inch (11.4-millimetre) calibre was completed. Firing trials carried out in April on the .32-calibre model using rimless ammunition having proved reasonably successful, Wardell wrote to the Master-General of the Ordnance, Major-General Milford,[9] and after some delay a meeting was arranged in Melbourne at which Colonel Barker,[1] Colonel Adams, Captain Dyer and Private Owen were to be present.

When Owen first presented his proposal to the army, it is certain that neither he nor his supporters fully appreciated the nature and extent of his immediate problem, which was twofold:

(*a*) to prove that his invention could be developed into a reliable weapon, and

(*b*) to convince the army that it required a weapon of the kind he was proposing.

At the time of this meeting much still remained to be done about (*a*) but in respect of (*b*) the situation had changed considerably: by now the army had come round to the view that it did need sub-machine-guns, but not Owen's.

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[6] V. A. Wardell, BSc. Acting Manager, Lysaghts Newcastle Works, Port Kembla Branch, 1939-46, Director since 1944. B. Melbourne, 13 May 1903.

[7] Capt C. M. Dyer. (1916-18: 1st AIF, and RAF.) Sec, Army Inventions Board 1940-42. Motor transport engineer; of Hawthorn, Vic; b. Hobart, 19 Oct 1876.

[8] G. S. Wardell, Chief Engineer, Lysaghts Works Pty Ltd, Port Kembla. B. Melbourne, 24 Oct 1904.

[9] Maj-Gen E. J. Milford, CB, CBE, DSO. (Served 1st AIF.) CRA 7 Div 1940; MGO AHQ 1941-42; GOC 5 Div 1942-44, 7 Div 1944-45. Regular soldier; b. Armadale, Vic, 10 Dec 1894.

[1] Brig L. E. S. Barker, CBE, DSO, MC. (Served 1st AIF.) CO 2/1 Fd Regt 1940-41; Dir of Arty AHQ 1941-42; BRA NGF 1942-43 and 1943-44, First Army 1943 and 1944-45. Regular soldier; of Mulgrave, Vic; b. Mulgrave, 5 May 1895.

At this meeting Owen was told for the first time of the major obstacle to the development of his gun. Milford explained that British Army experts, with far more experience than was available in Australia, were producing a sub-machine-gun that had already been given 12 months' testing and had proved an acceptable weapon. This was the Sten[2] gun, a version of the German Schmeisser.

A number of Sten guns together with full drawings and all manufacturing details were expected to arrive in Australia before the end of 1941. In the belief that the Sten would prove to be a well-finished gun of high quality similar to other types in current use the army was prepared to wait for it. In the event, it was found that the Sten had been hurriedly designed for cheap and rapid production, to meet the threat of invasion. In this process of simplification many standards of functional performance were abandoned under the pressure of the grave situation. Had Australian Army authorities known this at the time, they might have taken a greater interest in Owen's gun; but they were confidently awaiting in the Sten a weapon in the best tradition of British small arms design.

Before the Sten gun was designed no belligerent had even contemplated the development and production of small arms departing so far as did the Sten and Owen from the high standards of design and production hitherto considered normal. It is difficult to convey in a few lines, or even by means of photographs, the different degrees of sophistication of the Sten and the Owen and of the more conventional contemporary types such as the Thompson and the Schmeisser. To the expert the two types were worlds apart.

Later events were to show that in addition to the gun's deficiencies of design and finish, its development in Britain was not so far advanced as the Australian Army had been led to believe.

On the strength of the preliminary trials the Wardell brothers were convinced that the Owen gun had possibilities and that Lysaghts could make it if given the opportunity. Up to this stage Lysaghts had done all the technical and developmental work on the gun on their own initiative. Owen was paid a salary, and it was agreed that he would receive any royalties from the gun, which by now had been patented.[3]

There appear to have been extraordinary obstacles in the way of testing the gun properly, owing to almost endless confusion over the calibre required and over obtaining suitable ammunition. The choice of calibre was difficult to make; it lay ultimately between making the weapon work with ammunition already being manufactured in Australia, and adopting the 9-millimetre calibre which was standard for sub-machine-guns made in

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[2] The Sten was designed under the supervision of Col R. V. Shepherd, the Chief Engineer Armament Design (Small Arms) by a Mr Turpin, and takes its name from the initials of these gentlemen and the first two letters of the Enfield Small Arms Factory, where the prototypes were made. Similarly, the Bren got its name from Brno in Czechoslovakia where it was designed, and Enfield.

[3] Australian Patent 115,974. Owen received a substantial reward for his invention: Royalty at the rate of 5/- per gun amounted to about £11,000, which after taxation was reduced to £8,000. He then sold any rights to the gun to the Commonwealth for a sum of £2,000, which being capital was not taxed. This was one of the earliest awards made to inventors and was paid before the end of the war.

Britain. The latter course was finally agreed to and the manufacture of the ammunition in Australia begun; events proved that it was the correct decision. The army was, however, very slow in giving a lead in these matters, being more inclined to await the development of the Sten gun. Impatience with the delays in reaching this decision provoked questions in Parliament and comment in the press, and the Owen gun rapidly became a subject of controversy in the political world.

The Government now took an unprecedented and quite unorthodox step. It decided to take the matter out of the army's hands by placing an order for 100 Owen guns. This was a denial of the fundamental principle that the army should decide its own needs. The normal way would have been for the Directorate of Ordnance Production to place the order when instructed to do so by the army. What happened was that on 16th June 1941 the Minister for the Army, Mr Spender,[4] instructed the Master-General of the Ordnance to place the order. The army did not submit patiently to this overriding of its prerogative. The Military Board suggested that the order should not be placed but that further trials should be made. The Minister for the Army was adamant: the order stood and extensive trials on some of the first hundred Owen guns in both .45-inch and 9-millimetre calibres were carried out under the supervision of Lieut-Colonel Latchford at Long Bay Range on 29th September 1941. This time the performance of the Owen gun was thoroughly tested and compared with that of the Thompson and the imported Sten. Generally the Owen performed very well, and under extreme conditions—such as after being immersed in mud and water—much better than the other two. It gave definite promise of being a suitable and efficient weapon.

There would be little point in quoting the patent specifications of the Owen. A commentary on the specification kindly supplied by the Patent Office, Canberra, may give to anyone unversed in the language of patents a better idea of some of the gun's main characteristics:

THE OWEN GUN
(Patent No. 115,974)

The Owen gun was an automatic firearm of the usual recoiling breech bolt type, with a fire control member cooperating directly with the trigger.

Its outstanding features included:—

(*a*) extreme simplicity of design and construction, which enabled it to function successfully under difficult service conditions;
(*b*) the rapidity with which it could be taken to pieces and reassembled;
(*c*) the system of fire control which facilitated economical expenditure of ammunition;
(*d*) a tubular stock body and, in later models, a hollow breech bolt;
(*e*) high muzzle velocity, which helped to make the gun a very effective short-range weapon.

By placing the magazine on top the centre of gravity of the gun was made to coincide with the gun's longitudinal axis. This gave greater accuracy of fire under fully automatic conditions.

Another great advantage was gained from this placing of the magazine: if mud got into the weapon round the breech it would drop straight to the ground; if it

[4] Hon Sir Percy Spender, KBE. MHR 1937-51; Assistant Treasurer 1939, Treasurer 1940; Minister for the Army 1940-41, for External Affairs 1949-51; Aust Ambassador to USA since 1951. B. Sydney, 5 Oct 1897.

entered the magazine it either tended to drop out or was pushed out by the magazine spring. The Sten gun, on the other hand, was loaded on the side and ejected spent cartridges to the other side so that mud tended to lie in the bottom of the casing round the bolt. It was the Owen gun's ability to operate under muddy conditions that made it superior to other sub-machine guns in the jungle. All these advantages, combined with an unusual simplicity of design, singled the Owen gun out from its contemporaries and its predecessors.

On the strength of the September trials Mr Spender increased the order from 100 to 2,000. This was his last action as Minister for the Army before he was succeeded by Mr Forde,[5] a member of the newly elected Curtin Government. But the troubles of the Owen gun were by no means over. The manufacturers had underestimated the difficulties of securing the necessary machine tools, which were under the control of the Department of Munitions.

On 5th November 1941 the Sydney *Daily Telegraph* published an account of what it believed had been done to hinder production of the Owen gun. Here, the newspaper maintained, was a most promising Australian-designed weapon of a kind urgently needed, that was not being developed as rapidly as it should because of army opposition.

It is questionable how far public ventilation of technical matters in the midst of a war is a good thing. Chief justification for publishing stories of inefficiency in munitions production—a condition which can arise in any country at war—is that it may be expected to lead to the removal of the causes of inefficiency. The issue in the present instance, however, was not simply a matter of efficiency but of decisions on technical matters of some complexity. The reports were certainly not fair to the army since some of its experts, notably Colonel Latchford, were doing everything possible to help production along.

There can be little doubt that at this period the army was unduly conservative about the gun, but it was not long before it took fairly drastic action to put its house in order. Younger administrative officers with more recent experience of active warfare were placed in charge of the technical sections responsible for small arms. By mid-1942 there was effective liaison between the army and the manufacturers of the Owen gun.

Production of the Owen gun was held up not only by troubles over machine tools but also by protracted arguments concerning modifications of design suggested by the Directorate of Ordnance Production, which were intended to facilitate mass production and reduce the manufacturing time. In an attempt to settle the issues, the Minister for the Army, Mr Forde, who strongly supported the development of the Owen gun, called a conference in Melbourne on 24th November 1941 at which representatives from the army, Munitions Department and Lysaghts were present.

General agreement was finally reached, as a result of which Lysaghts had to put about seventy requests for minor changes of design through

[5] Rt Hon F. M. Forde. MHR 1922-46; Minister for Army 1941-45, Defence 1946; Deputy Prime Minister 1941-45; Prime Minister Jul 1945; High Commnr for Aust in Canada 1946-53. B. Mitchell, Qld, 18 Jul 1890.

the usual channels for the approval of the army and the Ordnance Production Directorate before the sealed drawings of the gun were ready for use. These changes did not, however, amount to the complete redesign of the gun advocated by the directorate.[6]

Among the matters brought up at the conference was the question of steel for the barrel of the gun. The Ordnance Production Directorate, in consultation with army experts, had altered the steel specifications drawn up by Lysaghts, which called for a good, approved ordnance steel then in production at Newcastle Steel Works and readily available. This steel, which had been used in the model guns made earlier, also had the advantage that its manufacture required no nickel, which was then very scarce. Lysaghts' original specifications were finally accepted.

While Lysaghts were struggling to get the Owen gun into production the army prudently placed an order for 20,000 Sten guns. It should be remembered that the Owen had not yet been tried out in battle, and had it failed the Master-General of the Ordnance would certainly have been held responsible for not exploiting the Sten. The Department of Munitions, in the early stages at all events, also tended to favour production of the Sten, because it considered that effort should be concentrated on one proven type of gun. In the department's view the superiority of the Owen had not been so marked as to warrant its exclusive production.

Allegations made at the time that some of the scarcity of machine tools experienced by Lysaghts was due to the parallel production of two sub-machine-guns can be given little weight. This shortage was felt in every munitions project, and moreover the Sten—or Austen as the Australian version was called—employed a large number of die-cast components; this meant that manufacturers of the two weapons were not competing for the same kinds of machine tools.

On making a detailed analysis of requirements for manufacturing the Sten gun the Directorate of Ordnance Production discovered that it was not in the advanced stage of development anticipated and that, in England, it had rapidly undergone changes and reached a Mark III model. The gun itself was, by customary standards for small arms, extremely crude having been designed for quantity rather than quality. The Australian contractors to whom the gun had been assigned, Die Casters Ltd (Melbourne), had, through the drive and enthusiasm of their technical manager Mr R. W. Newton, developed the technique of diecasting to a high degree of efficiency and by applying it to the Austen were able to attain a fast rate of production. Indeed the company claimed that the Austen could be produced in six man hours and a half, as compared with 37 man hours for the Sten. The Austen was so designed that it could be taken to pieces and reassembled in 15 seconds, a feature by which the army set great store. Newton reintroduced into the design certain features of the Schmeis-

[6] The object of O.P.D's proposed redesign was greater ease of production with the facilities available. For instance the barrel would have been broached in one or two operations thus facilitating mass production. The normal method of producing barrels up to that time had necessitated a larger number of operations with a consequent drop in the rate of production but greater precision in the finished article.

ser which Turpin had rejected when designing the Sten. His application of the die-casting technique represented a definite advance in manufacture. So also did several novel features which he added. Thus the pendulum swung from the relatively sophisticated Schmeisser to the rough-and-ready Sten and back again to the less austere Austen. The ingenuity displayed by the manufacturers of both the Austen and the Owen gained for Australia a notable reputation for its work on sub-machine-guns.

Figures for the output of sub-machine-guns were:

Owen, Mks I and II	Lysaghts Pty Ltd, Port Kembla, NSW .	45,477
Austen, Mks I and II	Die Casters Ltd, Vic, and W. T. Carmichael Ltd, NSW	19,904

Soldiers who used both Austen and Owen guns in the South-West Pacific Area were, it appears, in favour of the Owen. In Latchford's view, the handiness of the Owen put it out in front. It still had one or two minor defects when first used in New Guinea—reports on operations in the Aitape-Wewak campaign mention defects arising from the design of the safety catch—but on the whole the Owen was the more reliable of the two guns in that after immersion in mud and slush it could still be relied on to fire. The Austen could not. In time the Owen became the "forward area" weapon.

An authoritative assessment of the qualities of the Owen gun is to be found in the report of tests conducted by the Ordnance Board of Britain during December 1943. In competition with five other guns, the Owen was rated first in four of the five tests and first in over-all order of merit.

The Owen survived long enough to be used in the Korean war of 1952, where it was still highly regarded by the men who used it. Its reputation was such that Mr Blunden,[7] Scientific Adviser to the Military Board, planned operational research on the Owen with a view to comparing it with what was then the latest British development in sub-machine-guns—the Patchett. While the Owen certainly justified the hopes and efforts of those who worked so enthusiastically to have it introduced during the war, it is not difficult to sympathise with the caution shown by army and munitions officers who were anxious that the country's production potential should not be squandered in making a weapon about which at that time they had doubts. However the gamble was successful and the gun proved a major contribution to British small arms design.

The uncertainty and disagreements which surrounded the Owen gun in the early phases of its development brought about one notable reform. It forced on the army authorities and the Government a realisation of the need for some means of rapidly and authoritatively assessing inventions, not only for their technical feasibility but also for their possible usefulness to the armed services. The maladroit handling of the Owen gun by the Army Central Inventions Board was one of the main reasons for setting up the Army Inventions Directorate, a civilian body which took a more realistic and helpful attitude towards inventors.

[7] Lt-Col W. R. Blunden, BSc, BE. DADME (RDF) MGO Branch LHQ 1943-44, Att Admiralty Gunnery Estab as Design Engr 1944-45; Scientific Adviser to Aust Mil Board since 1952. B Sydney, 18 Jun 1916.

CHAPTER 16

AMMUNITION AND EXPLOSIVES

THE manufacture of ammunition necessarily formed a large part of the munitions program, for two reasons: firstly, because of the wide variety of items that came within its scope—the ammunition for guns and rifles as well as hand grenades, land mines, naval mines and torpedoes; and secondly, because of the great quantities of each item required, running in some instances into many millions. If the extent of an industrial effort can be measured roughly by its cost, then about one third of the 1939-45 munitions effort in Australia went into ammunition: expenditure on factories and equipment for making ammunition amounted to about £45,000,000, while the cost of the ammunition itself was approximately £41,000,000.[1] It involved the Government in the construction of 11 major factories, 16 smaller ones and 90 annexes, and in the employment of over 50,000 persons.

A typical round of ammunition made at this period was that for the 3.7-inch anti-aircraft gun. The accompanying diagram shows its main components and at the same time indicates the extensive nature of the industries upon which its manufacture was based. The round will be seen to have consisted of:

(*a*) metal components: the cartridge case, shell body, primer body and fuse;

(*b*) explosive components: initiators (lead azide and mercury fulminate), igniters (gunpowder), propellant (cordite WM), booster (tetryl) and high explosives (TNT).

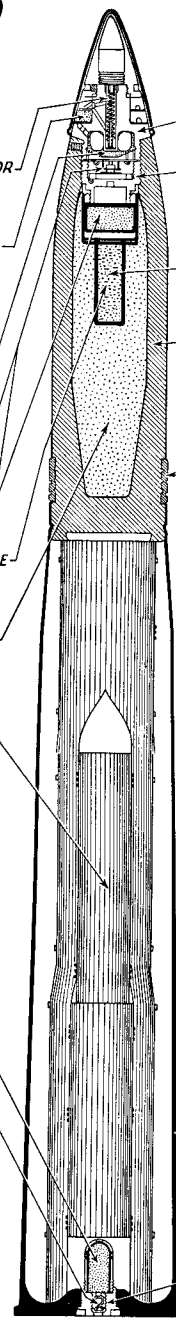
The raw materials from which these components were made are shown on either side of the diagram.

Small-arms ammunition and the cartridge cases of gun ammunition were made exclusively in the government factories, first at Footscray where the manufacturing technique for small-arms ammunition had been established in 1888. Cases were made by the traditional method of drawing in a press from a disc of brass cut from a rolled sheet. The only way of being certain that the walls of a case were of the requisite, uniform thickness and that they would retain their dimensions on storage,[2] was to begin with rolled sheet having precisely the chemical composition and physical properties specified. Manufacture of this sheet required an unusually high degree of scientific control, which was one reason why it was restricted to government factories. The capacity of the parent factory at Footscray

[1] The total expenditure on munitions was about £271,000,000 (see *Munitions Digest*, June 1945, p. 48).

[2] Unless properly treated, metals shrink and warp on long standing.

3·7" H.E.~A.A. ROUND



FUSE

GAINE

SMOKE BOX

SHELL BODY

DRIVING BAND

CARTRIDGE CASE

PRIMER

Nitric Acid
Mercury
Ethyl Alcohol
Potassium Chlorate
Mercury Fulminate
Antimony Sulphide
DETONATOR

Potassium Nitrate
Sulphur
Charcoal
Graphite
FUSE POWDER

Charcoal
Potassium Nitrate
Sulphur
GUN POWDER

Sodium
Ammonia
Lead Nitrate
Lead Azide
DETONATOR

Iron
Nitro-Benzene
Hydrochloric Acid
Sulphuric Acid
Aniline
Methyl Alcohol
TETRYL C.E.

Red Phosphorus
Mineral Jelly
SMOKE MIXTURE

Nitric Acid
Toluene
Sulphuric Acid
Nitric Acid
Di Nitro Toluene
Sulphuric Acid
T.N.T.

Nitric Acid
Cellulose (Wood)
Sulphuric Acid
Chalk
Nitro Cellulose
PROPELLENT

Nitric Acid
Crude Glycerine
Sulphuric Acid
Nitro Glycerine

Ethyl Alcohol
Coke
Chlorine
Aniline
Diphenyl Diethyl Urea
(Carbamite)
Mineral Jelly

Charcoal
Potassium Nitrate
Sulphur
GUN POWDER

Potassium Perchlorate
Antimony Sulphide
Sulphur
Glass
Q.F. CAP COMPOSITION

Metals used in these components

Steel
Copper
Zinc
Lead
Aluminium
Tin
Antimony

Other Materials

Paper
Cloth
Webbing
Silk Thread

Dept. of Defence Production

proved much too small to satisfy the wartime demands, and the following factories were therefore built and began operations on the dates shown:

Hendon, S.A.	Nov 1940
Finsbury, S.A.	Feb 1941
Rocklea, Qld	Nov 1941
Welshpool, W.A.	Aug 1942
Albury and Wagga, N.S.W.	Sep 1942
Port Pirie, S.A.	Oct 1942
Rutherford, N.S.W.	Oct 1942
Goulburn, N.S.W.	Nov 1942
Derwent Park, Tas	Dec 1942
Broken Hill, N.S.W.	Jan 1943
Tamworth, N.S.W.	Feb 1943
Mildura, Vic	Mar 1943
Kalgoorlie, W.A.	Oct 1943
Hay, N.S.W.	Apr 1944

The manufacture of shell bodies by the well-established hot forging process was undertaken by the Ordnance Factory at Maribyrnong in the early thirties as part of the program to make the 18-pounder gun. As described

GOVERNMENT AMMUNITION FACTORIES

VICTORIA

Footscray: Parent factory.
Mildura : Primers.

QUEENSLAND

Rocklea : ·303, ·380, ·455 Ammunition. Smoke shells - 25 Pdr. Q.F. Cartridge cases

TASMANIA

Derwent Park : Cartridge cases 2 in. mortar bombs.

NEW SOUTH WALES

Broken Hill : Fuses
Rutherford : Cartridge cases. Shells - 4 in. Naval. 25 Pdr. 5·5 in. forging.
Goulburn : Shot, Fuses. Shell - 25 Pdr. Oerlikon Tracer
Albury : Fuses
Tamworth : Primers
Wagga : Fuses
Hay : Fuses

SOUTH AUSTRALIA

Hendon : ·303 Ammunition
Finsbury : Cartridge cases Fuses
Port Pirie : Shells - 25 Pdr.

WESTERN AUSTRALIA

Welshpool : ·303 Ammunition.
Kalgoorlie : 40 mm. A.A. Bofors shell.

earlier, a similar process capable of adaptation to the making of shell bodies was developed by Stewarts and Lloyds in their seamless tube plant at Newcastle. One of the chief problems in extending the manufacture of shell bodies to commercial industry was the provision of suitable hydraulic presses. Australia was able to import machines of the most modern design from Baldwin Omes in the United States.

The Directorate of Gun Ammunition, under the leadership of Mr W. J. Smith, one of Australia's leading production engineers, organised the manufacture of shell bodies by commercial industry with great efficiency, pressing into service the resources of all the State railway workshops, the steel industry, and other private engineering firms.

Relatively simple in design and comparatively easy to make, primer bodies were made in millions by commercial industry. So also were fuses,[3] though these were a good deal more complicated than primers.

The number of rounds of the various types of ammunition produced in Australia between 1940 and 1945 is set out below:

Small arms	1,845,000,000
Light anti-aircraft	3,784,695
Heavy „ „	575,222
Light artillery	1,521,411
Medium „	8,021,850
Heavy „	131,725
Mortar bombs	3,993,011
Grenades	5,521,594
Aircraft bombs (practice)	1,840,719
„ „ (service)	147,718
Mines (land)	750,098
„ (naval)	12,336

While all this ammunition was manufactured in strict conformity with British specifications and designs, considerable latitude was permissible to allow for local materials and processes so long as the finished articles possessed exactly the desired characteristics. Fabrication of metal components presented few difficulties and called for very few innovations. In the manufacture of explosives on the other hand, there were many interesting technical developments and for this reason they will be discussed at some length. As these processes were potentially extremely dangerous they were confined to the government factories and to an annexe conducted for the Government by I.C.I.A.N.Z.

Until the second world war Australian commercial and military explosives were made only in Victoria.[4] In the open spaces of Deer Park on the outskirts of Melbourne the manufacture of commercial explosives was begun in 1874 in response to the needs of the flourishing gold-mining industry. Nitroglycerine formed the essential basis of explosives used in mining and quarrying. After many vicissitudes the young industry passed in 1925 into the hands of Nobels (Australia) Pty Ltd, which was later merged with I.C.I.A.N.Z. After extensions had been made to the plant in 1935, the output of explosives was greatly increased and within three years it was producing blasting gelatine, dynamite and gelignite at the rate of about 8,000 tons a year—sufficient to meet Australia's requirements of these materials.[5] Many chemical operations used in making commercial

[3] A fuse (sometimes spelt fuze) is any device for initiating the explosion of a shell, bomb, grenade, etc.

[4] Mr W. H. Coulson and Mr D. W. Finley have given me valuable help with this chapter.

[5] These explosives were all based on nitroglycerine. Their approximate compositions were as follows:

	Blasting gelatine	Dynamite	Gelignite
Nitroglycerine	92%	75%	60%
Collodion cotton	8%	—	5%
Kieselguhr or diatomaceous earth	—	25%	—

Gelignite contained in addition 27% potassium nitrate and 8% wood meal.

explosives were also used in making military explosives, and although in Australia the two industries were conducted separately in peacetime, I.C.I.A.N.Z. was able to provide valuable assistance to the Government during the war. Moreover the company could call upon the great fund of technical experience of its parent organisation, Imperial Chemical Industries, which for many years had made both industrial and military explosives on a large scale at Ardeer, in Scotland.

The manufacture of military explosives in Australia began much later than that of commercial explosives. In 1910, in pursuance of the policy of self-containment in defence, the Commonwealth Government built a factory at Maribyrnong near Melbourne for the manufacture of small-arms cordite. Like the dynamites, cordite was based on nitroglycerine. By itself, nitroglycerine was, as Nobel found when he first began to manufacture it in 1863, extremely dangerous to handle, both during manufacture and in the course of transport, and many serious accidents occurred. In 1867 he discovered that nitroglycerine could be made safer to handle by mixing it with kieselguhr, an inert substance; also, and more surprisingly, that when mixed with gun cotton (nitrocellulose), itself a powerful explosive, it formed a relatively slow-burning propellent. A colloidal dispersion of nitrocellulose in nitroglycerine formed by means of a solvent such as acetone or by mechanical working under suitable conditions of temperature and pressure, would not burn to detonation although it could be readily detonated by explosives, such as mercury fulminate, which were referred to as initiators. Until about 1930 all cordite was made by the "dry mixing" process, so called because the first step consisted of mixing dried nitrocellulose in the form of a creamy-white, friable powder, with liquid nitroglycerine. Insofar as it involved handling dry nitrocellulose there was an ever-present element of danger at this stage of manufacture. In the wet condition nitrocellulose was perfectly safe to handle; once dried it became sensitive to mechanical and thermal shock, either of which might cause it to take fire and explode. Dried nitrocellulose was always mixed by hand since the resulting paste was too sensitive to be safely handled in any form of mechanical mixing equipment. The second step in the process consisted of bringing the paste into a gelatinous condition, which was done by first moistening it with acetone, when it became less sensitive to mechanical shock, and then pounding it in a mixing machine for several hours until it was transformed into a homogeneous, yellowish-brown, translucent mass. At this point a stabiliser—mineral jelly—was added. This combined with and rendered innocuous certain substances which would be liberated by deteriorating cordite and cause a spontaneous explosion.[6] This type of cordite was discarded about 1915 because its high flame

[6] Mineral jelly owed its stabilising action to the presence in it of unsaturated hydrocarbons, the proportion of which was frequently deliberately increased by a process known as "cracking". The stabilised material, commonly referred to as "dough", was extruded in the form of cords (hence the name cordite) from which the volatile solvent (acetone) was allowed to evaporate at a temperature of not more than 43°C. This, very briefly, was the process used by the Explosives Factory Maribyrnong in 1912 when it began to manufacture cordite Mark I at the rate of about 50 tons a year for small-arms ammunition. As part of its original program the factory also made mercury fulminate, the sensitive initiatory explosive used on the percussion caps of small-arms ammunition.

temperature tended to cause serious erosion in gun barrels. This tendency was lessened by reducing the proportion of nitroglycerine in the mixture from 58 to 30 per cent, to produce cordite M.D.

As part of the program for increasing the production of munitions in the late twenties, the activities of the factory were extended to include the manufacture of a third class of explosive, namely high explosive (H.E.) used in bursting shells, bombs and mines. This differed from propellants in that its rate of burning was so rapid as to be almost instantaneous, with the result that it detonated with a shattering effect. In 1928 Maribyrnong began to make T.N.T., a substance which was still, in spite of many others that had since been developed, the most important of military high explosives. T.N.T. did not deteriorate on long storage; it melted at a relatively low temperature (80 degrees centigrade) and could be readily poured into shell bodies and other containers. It was not without drawbacks—it shrank on solidifying and thus tended to leave cavities, and it was poisonous—but these were outweighed by its advantages.

An essential quality of a military explosive was that it must not deteriorate on storage. Commercial explosives were rarely stored for long periods before use, but military explosives often were. Cordites were the most unstable explosives in common use and it was only by using raw materials of uniformly high quality, by exercising the greatest care to avoid the introduction of impurities during their manufacture and by adding to them special substances known as stabilisers, that the risk of deterioration during storage could be overcome. Though the cause can never be known with certainty, experts agree that the blowing up of the battleship *Bulwark* in 1914 and of the cruiser *Natal* a year later was due probably to a spontaneous explosion in deteriorating cordite. Testing of cordite for evidence of deterioration was therefore absolutely essential.

It was in this connection that the first scientific laboratory to be associated with the Commonwealth Department of Defence was set up in 1910 on the recommendation of Mr C. Napier Hake, Chief Inspector of Explosives in Victoria and Chemical Adviser to the Department of Defence. Located in what had been a guard house, at the south gate of Victoria Barracks, the laboratory was at first concerned almost solely with routine surveillance tests on the storage of cordite and other explosives in the various defence magazines throughout Australia.

The laboratory's activities continued until 1921, when it was included within the Munitions Supply Branch as the Explosives Section and became one of the most active and the most important units of that organisation. The section's main functions were to ensure that the products of the Maribyrnong factory conformed with Service specifications, and to study the conditions necessary for the safe storage and transport of explosives.

In 1935 the Maribyrnong factory undertook the manufacture of naval cordite (cordite S.C.).[7] This was more than simply another item on the production list: it represented a distinct advance in manufacturing achieve-

[7] SC stands for solventless, carbamite.

ment and a new level of confidence in the capabilities of the Munitions Supply Board. As already mentioned, the Australian Navy depended on Britain for all its warlike supplies, and it was reluctant to change this arrangement. The rigid system of inspection imposed by the Royal Navy applied to ammunition carried not only by its own ships but also by any ships manoeuvring with them; a ship whose magazine could not be relied on might be a danger to other ships in the vicinity, and as cordite was often stored for long periods on ships its stability had to be above suspicion.

The time required to burn a given quantity of cordite in a gun could be controlled by adjusting the ratio of its surface area to its volume. In a rifle cartridge, for example, cordite usually took the form of a bundle of fine, thin-walled tubes about the thickness of a darning needle, the wall thickness being so chosen that the charge was burnt out just before the bullet left the relatively short rifle barrel. On the other hand, in a large gun of long bore such as a naval gun a longer time of burning was called for. The charge was therefore built up of thicker cords.

When thick cords were made by the original process the time required to dry out the solvent (acetone) might be as long as several weeks which meant that large quantities of cordite had to be held in manufacture. To avoid this the Naval Cordite Factory at Holton Heath (England) introduced the solventless process, which avoided the use of a volatile solvent and had the special advantage of being much safer than the dry process because the first step consisted of mixing nitroglycerine and nitrocellulose under water.

Innovations introduced at the same time brought with them other advantages. Especially notable was the substitution of carbamite for mineral jelly as a stabiliser: carbamite was a more efficient stabiliser and also acted as a partial gelatiniser. It was added before the nitrocellulose-nitroglycerine mixture was dried, a procedure which represented a considerable gain in safety. In the second step the water was drained off and the material, in the form of a thin sheet supported on a wire gauze, was allowed to dry. Gelatinisation was completed, not by means of a solvent but simply by passing the sheet between rollers heated to 55 degrees centigrade, after which it was taken to a still higher temperature (70 degrees) and finally extruded in the form of thick cords. The increased safety of the first step was offset to some extent by the risk of fire which attended the rolling operations. The solventless process possessed still another advantage over the older process: it avoided shrinkage and distortion of the cordite. Dimensional stability was conducive to good ballistics; in other words charges of cordite which remained identical in size and shape could be relied upon to reproduce exactly a given muzzle velocity in a projectile.

By the end of 1935 the Maribyrnong Explosives Factory, though still dependent on outside supplies for some of the raw materials, was manufacturing cordite S.C. of a quality acceptable to the Admiralty. It had also successfully developed and brought into production most of the important types of military explosive then in general use, and had assembled a staff

well trained in the manufacture and in the techniques of filling ammunition. A nucleus from which a wartime explosives industry could grow was thus well established.

Calculations based on the assumption that the defence forces should be prepared for a "minor scale of attack"—the officially-accepted view—revealed that the capacity of the government factories for producing cordite and T.N.T. (which was at the rate of 1,500 and 600 tons per annum respectively) fell short of requirements. After considering several alternative proposals for decentralising the manufacture of these explosives, which up to this time had been made only at Maribyrnong, the Principal Supply Officers' Committee at a meeting on 23rd August 1938 favoured a proposal that I.C.I.A.N.Z. should be asked to build an annexe to its Deer Park factories. This proposal had much to recommend it: adequate technical staff could be provided by the company; nitric and sulphuric acids, some accessory equipment services, power and steam could be supplied from the company's neighbouring plants, and the proposed site was well suited to the purpose. Four days before the outbreak of war the Minister for Supply and Development, Mr Casey, approved the scheme, and shortly afterwards the Commonwealth Government entered into an agreement with I.C.I.A.N.Z. for the construction of an annexe (Armament Annexe No. 29—later known as No. 5 Government Explosives Factory, Albion), designed in the first instance for an annual output of 2,000 tons of T.N.T., 1,000 tons of cordite, and 250 tons of carbamite.

Carbamite, a key substance whose importance in the manufacture of cordite has already been alluded to, was new to the Australian chemical industry, but not beyond its capacity, thanks to the well-developed chlorine industry at Yarraville. One of the starting materials used in its manufacture was phosgene (a poison gas used in the first world war) which was made by the interaction of chlorine with carbon monoxide. It may help to clarify the nature of the important wartime developments in the manufacture of cordite if, at this point, the processes in operation at Maribyrnong in 1939 are briefly recapitulated, in the accompanying table.

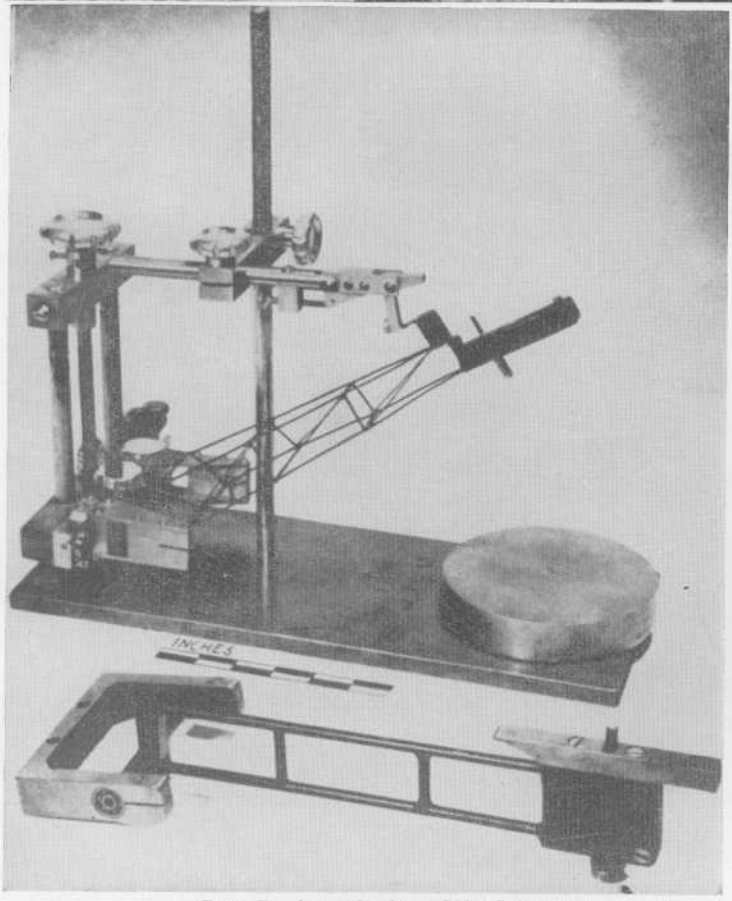
LAND SERVICE CORDITES	NAVAL CORDITE
CORDITE MD, made by dry mixing process. *Gelatinised with acetone.* Stabiliser (mineral jelly) added during gelatinisation.	CORDITE SC, made by *wet mixing process.* *Stabiliser (carbamite) added during wet mixing.* Gelatinised by rolling at 55-75 deg C.
CORDITE W, made by dry mixing process. Stabiliser (carbamite) added to dry mix during gelatinisation. *Gelatinised with acetone.*	*Note*: The safe processes are shown in italics.

The factory at Albion was to be used for the manufacture of cordite W, and the intention was to evolve a method which would combine the safer



(*L. J. Hartnett*)

Profile turning outside of a shell.



(*From Bowden and others, CSIR Bulletin No.* 173, *plate* 1)

Pendulum hammer apparatus used in experiments on the initiation of explosives.



Wirraway. (*C.A.C.*)



Boomerang. (*C.A.C.*)

steps in the manufacture of the other types of cordite, namely: wet mixing using carbamite as the stabiliser; and gelatinisation by means of a volatile solvent. Such a process had been tried out in the United Kingdom some years previously but had never been used there on a large scale. There would have been little difficulty in putting it into operation at Albion had it not been for the fact that carbamite could not be imported at the time and was not yet being made locally.

A way out of this difficulty was to try to make cordite M.D. (which was an acceptable substitute for cordite W) by a wet process. Wet mixing became safer still if a stabiliser was added before the material was dried. This presented no difficulty with carbamite but at that time it had nowhere been satisfactorily achieved with mineral jelly. Mr Leighton, the Consultant on Explosives, suggested that an attempt should be made to overcome this difficulty. The problem was referred to the Developmental Laboratory at the Explosives Factory Maribyrnong where it was satisfactorily solved by a team working under the direction of Messrs Cochrane[8] and Coulson.[9] Molten mineral jelly was injected by means of steam into a well-stirred aqueous suspension of nitrocellulose. After nitroglycerine had been added the mixture was dried and gelatinised with acetone in the usual way. The new process was immediately adopted at Maribyrnong and soon afterwards at Albion. The effect of this important discovery was that it became possible to make all types of land-service cordite in the wet process plant at Albion under significantly safer conditions. By 1942 all types of cordite in production in Australia were being made by processes adapted to the initial wet mixing of nitrocellulose and nitroglycerine, a notable contribution to a higher level of safety in the industry. The absence of serious accidents from the wartime industry may be attributed in part to these technical developments.

While the Albion annexe was being built a great deal of discussion went on between the Advisory Panel on Industrial Organisation and officials of the Department of Supply, about the desirability of a second filling factory. To decentralise manufacture of military explosives but to neglect to decentralise "filling" factories was, in the eyes of the industrialists, only a half measure. Destruction of Maribyrnong filling factory, the only one in the Commonwealth, either by an accidental internal explosion or by enemy action, would, they argued, jeopardise the whole defence scheme. The panel strongly urged, therefore, the construction of a second filling factory at Albury. Department officials, on the other hand, while well aware of the force of these arguments, were anxious to defer such a step until they had provided the immediate needs of the fighting services. Their estimates were that it would be two years after beginning construction before a second filling factory would come into operation. Current expan-

[8] J. R. S. Cochrane, BSc. Asst Manager, Explosives Factory Maribyrnong, 1928-41; Manager Explosives Factory, Salisbury, 1941-45; Leader, Aust Scientific and Technical Mission to Germany, 1946-48; General Manager, Explosives Factories, 1950-55. Of Melbourne; b. Melbourne, 11 Aug 1891. Died 3 Oct 1955.

[9] W. H. Coulson. In charge of Developmental Labs Explosives Factory Maribyrnong 1938-44; Aust Munitions Representative in London 1945-50. Of Melbourne; b. London, 3 Nov 1901.

sion at Maribyrnong and at Albion, they pointed out, would make it difficult to secure the technical staff necessary to construct and operate the second filling factory.

Then there was the question of its site. Climatic conditions favoured Victoria. Some air-conditioning would be necessary wherever it was built, but it would be a good deal less in Victoria than in any other of the mainland States. Places farther north than Newcastle, New South Wales, were ruled out completely because of high temperatures and humidity. Albury, Bendigo and Ballarat were suggested, but throughout the period of the "phoney war" discussions ranged on without any decisive result. It was not until June 1940 that any positive action was taken.

Within the newly created Department of Munitions a Directorate of Explosives Supply was set up and placed under the direction of Mr Donaldson, a technical director of I.C.I.A.N.Z. Donaldson was a man with wide experience in the explosives industry at high technical and directive levels, gained first at Nobel's Ardeer factory in Ayrshire, later at the Modderfontein Dynamite Factory in South Africa, and as Technical Managing Director, Explosives Group, of I.C.I. in London. A dour Scot whose dialect was sometimes hard to follow, Donaldson had great physical and mental vigour, and outstanding administrative capacity. His immediate task was to create a large organisation capable of dealing with the many diverse problems associated with the design and erection of factories for making propellants, high explosives and pyrotechnics, as well as with the technicalities of filling and assembling ammunition. He was fortunate in having as his departmental adviser Mr Topp, who as Manager of the Maribyrnong Explosives and Filling Factory had had long experience with military explosives and knew the departmental procedures from A to Z. Mr Grist,[1] and later Mr Finley,[2] became Donaldson's personal assistant.

The Directorate of Explosives Supply differed from the other directorates of the Department of Munitions in that it was concerned entirely with designing and building factories but had no functions of management. Other directorates designed, built and managed their factories through Boards of Area Management; the factories built by the Directorate of Explosives were operated by the Department of Munitions. The purpose of this arrangement was to relieve the managements of government explosives factories from the work of designing and building new factories, so that they could concentrate on production.

Donaldson's technical experience had been gained almost exclusively with the construction and operation of plants for making commercial and military explosives. Topp, on the other hand, was experienced both in the manufacture of explosives and in the filling and assembly of the components into ammunition, and he was fully acquainted with the design of factories for making war material such as pyrotechnics, land mines and

[1] J. M. Grist. Works Manager, Nobel Explosives Factory, Deer Park, to 1945. B. Petersfield, Eng, 5 Jun 1883. Died 31 July 1951.

[2] D. W. Finley, MA, BSc. Factory Superintendent, Bogawantalawa District Tea Co Ceylon; Personal assistant to Dir Explosives Supply 1941-45; Manager, Information Service ICIANZ Ltd, since 1945. B. Ryde, Isle of Wight, 21 Jan 1912.

bombs. In many ways their experience was complementary, and each possessed a temperament that made for good team work.

Some indication of the extent of the new demand for explosives which sprang up almost overnight, may be had from the fact that tentative estimates made by the Controller of Production Orders and Statistics, Mr S. K. Menzies,[3] on advice from the Service Chiefs, called for an increase in the annual output of T.N.T. from 1,600 tons to 9,000 tons, and of cordite from 2,500 to 10,000 tons. Many other items were required, but these were the principal ones, and to provide them new factories would be needed.

The question of the adequate and continuous supply of chemical raw materials for the operation of the explosives and filling factories was now thrown into sharp relief.

> It does not require a very close examination (wrote Leighton at this time) to find that the factories now operating, small as they are compared with those that will be, already put a strain on supply. A disconcerting factor is that of surprise—one day it is glycerine, the next nitrate of soda, and so on. There seems to be no watch tower, no one to give a reliable account of how supply of armament chemicals is or will be.

The result of this memorandum was the appointment of a permanent Armament Chemicals Committee to keep watch over and report upon, and recommend measures in relation to, the supply of all chemicals needed by the Department of Munitions.[4] The need to plan supplies of raw materials for the government explosives factories had of course been recognised long before this committee came into being, but the new developments demanded a more systematic attack on what was a very much larger problem.

Those planning the new explosives factories, following the precedent set at Maribyrnong, adopted the method of making nitric acid—a key chemical of the industry—from nitrate of soda and sulphuric acid as the most practicable in the circumstances. More than thirty retorts for making nitric acid, capable of consuming between them 20,000 tons of nitrate of soda a year, were built and set up near the main factories. However the planners were fully aware that the great weakness of this arrangement was its dependence on imported Chilean sodium nitrate and the problem of disposing of "salt cake", a by-product of the process. This weakness was emphasised by the growing threat to shipping across the Pacific and the increasing difficulty of obtaining American dollars. In the course of discussions within the directorate it was pointed out that the explosives program required an annual importation of 45,000 tons of nitrate, payment for which would have to be made in dollars equivalent to £850,000 Australian.

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[3] S. K. Menzies. Executive G. J. Coles and Co 1931-39; Dir Production Orders and Statistics Dept of Munitions; and Services-Munitions Coordination Cttee, 1940-45. Of Melbourne; b. Jeparit, Vic, 23 Jul 1905.

[4] Members of the committee were: A. E. Leighton (Chairman); H. P. Breen (Asst Secretary, Dept of Munitions); H. C. Green (Controller of Materials Supply); Dr J. Vernon (representing commercial industry); Dr I. W. Wark (CSIRO); E. J. Drake (Asst Controller Industrial Chemicals) (Secretary).

At the Deer Park factory I.C.I.A.N.Z. had already begun to exploit atmospheric nitrogen as a source of nitric acid, converting it first by the Haber process to ammonia and then by atmospheric oxidation to the acid. On 12th August 1941 Donaldson presented a complete scheme for the production of nitric acid and ammonium nitrate. He proposed as a first step to erect plants for the oxidation of ammonia. The intention was to use about half the Australian output of by-product ammonia (from coke ovens and gas works) calculated to yield about 13,500 tons of nitric acid a year, until synthetic ammonia should become available. The nitric acid so obtained would be at the expense of the ammonium sulphate ordinarily used in agriculture.

After considering a recommendation by the Director-General of Munitions on 10th October 1941, the War Cabinet approved the construction of four synthetic ammonia and ancillary plants by I.C.I.A.N.Z. under the supervision of the Directorate of Explosives supply. It was decided that at the same time three units for the production of synthetic methanol and for its distillation should be built in association with the ammonia unit. The estimated cost of the whole project was £2,500,000. The installations were to be distributed as is shown in the accompanying table.

	Synthetic Ammonia	Methanol	Ammonium Nitrate	Oxidation of Ammonia
Villawood . .	1	1	1	1
Mulwala . .	1	1		1
Albion . . .	1	1		1
Ballarat . .	1		1	1

In making this decision it was anticipated that with the inevitable falling off in the demand for nitric acid after the war, the ammonia plants could be turned over to the production of ammonium sulphate as a fertiliser for agricultural purposes, while the methanol plants would be of value in the plastics industry. Since, under the new scheme, sulphuric acid would not be needed for making nitric acid but only for concentrating it, there would be a smaller demand for imported elemental sulphur. Furthermore, the new industry would permanently preserve the country's capacity for making a chemical of key importance for defence.

The necessary equipment was of highly specialised and complicated design, and I.C.I.A.N.Z., as the only firm in Australia with expert knowledge concerning it, was given the responsibility of constructing four synthetic ammonia and three synthetic methanol units, together with four units for the oxidation of ammonia to nitric acid at atmospheric pressure and two for the production of ammonium nitrate. The synthetic ammonia plants were designed to have an annual capacity of 3,000 long tons of ammonia, together with 450 tons of methanol. Alternatively 900 tons of methanol could be produced if it were so desired, but at the expense of the output of ammonia, which would be reduced to 2,550 tons. It was decided to use by-product ammonia while awaiting the completion of the synthetic ammonia plants.

A survey of the capacity available in Victoria and New South Wales for the production of purified by-product ammonia having revealed that it was far from adequate to meet likely demands, additional plants were installed in the Metropolitan Gas Works in Melbourne, the Australian Gas Light Company in Sydney, and Australian Iron and Steel, Port Kembla. Arrangements were made with the Ammonia Company of Australia Pty Ltd in Sydney and the Victoria Ammonia Company in Melbourne to increase their production by about 25 per cent. Use was also made of the government annexe operated by Timbrol Ltd at Mortlake, New South Wales, to augment supplies. Oxidation of ammonia was carried out at atmospheric pressure in the presence of a platinum rhodium catalyst, a process which furnished an acid of about 50 per cent strength. Weak nitric acid from this source was later concentrated by mixing it with a strong sulphuric acid and distilling strong nitric acid from the resultant mixed acid.

The first unit for making nitric acid from ammonia was completed at Ballarat in November 1942; then followed one at Villawood (in March 1943), Mulwala (in October 1943) and Albion (in July 1944). It will be seen that most of these units were completed at the peak of the activities of the Directorate of Explosives Supply. The ammonium nitrate unit at Ballarat came into operation in March 1943 and that at Villawood in April 1943.

Owing to the uncertainty of shipping and the long delays in obtaining equipment from the United Kingdom, the Directorate of Explosives Supply decided as a matter of policy that as much as possible of the equipment for the synthetic ammonia plants should be manufactured in Australia, even though some of the items had not previously been made in this country. Australian engineers were thus committed to a somewhat daring undertaking, considering the facilities available. The Newcastle steelworks of the B.H.P., in conjunction with Australian Iron and Steel Ltd of Port Kembla, undertook the manufacture of hollow steel forgings of nickel-chromium steel for the main converters, the design of the converters being modified to meet the maximum capacities of the local steel manufacturers. The operation of piercing the 80-ton ingot poured by the B.H.P., and creating a bottleneck at both ends—one of the trickiest operations in forging—was carried out under the direction of Mr Merrett by Australian Iron and Steel. For the Australian steel industry—indeed for any steel industry—this was an achievement of a high order. It was an operation which was at that time being undertaken by only one firm in the United States, though the technique was better known in Europe. The smaller hollow nickel-chromium steel forgings were made by the Commonwealth Steel Company Ltd, while thick-walled high-pressure piping, capable of withstanding pressures of up to 300 to 400 atmospheres, was made by Stewarts and Lloyds.

The synthetic ammonia and methanol plants at Mulwala were the first to be completed (in June 1944), by which time the amount of ammonia being requisitioned was sufficient to keep only one of the four plants in

operation. Consequently it was decided that as each plant was completed it would be "run in" until it was proved. Albion was ready by May 1945 and Ballarat in June 1945. While the construction of these installations was a first-class technological achievement under difficult conditions, and while it contributed greatly to the defensive potential of the country, it came too late to play any significant part in the war. Most of the 40,000 tons of nitric acid used in the explosives industry during the war came from imported Chilean nitrate; only about 10 per cent was obtained from the oxidation of by-product ammonia. The amount made from synthetic ammonia and used in war production was quite small—probably not more than 10 per cent of the acid made by the oxidation of ammonia from all sources.

One of the last recommendations made by Donaldson before he resigned the Directorship of Explosives Supply in February 1944, was that the four synthetic ammonia plants should be equipped for the production of ammonium sulphate for use as a nitrogenous fertiliser, for which there would be a large market after the war. This the Government agreed to do, allocating £400,000 for the purpose.

As explained in an earlier chapter, the conversion of glycerine, cellulose and toluene into the corresponding explosive nitro compounds entailed the use of nitric acid, together with sulphuric acid, preferably in the form of oleum—sulphuric acid containing more sulphur trioxide than corresponded with the formula H_2SO_4.[5] Like nitric acid, oleum was inconvenient to transport and special plants for its production had to be built as close as possible to the explosives factories. Additional plants were required in any event since the peacetime needs were only a fraction of those for war. Oleum plants using elemental sulphur as a raw material were erected by Commonwealth Fertilisers and Chemicals Ltd at Ballarat and Villawood. The 23,000 tons of oleum required each year by the Albion and Maribyrnong factories was produced in the main works of Commonwealth Fertilisers at Yarraville, Victoria, while supplies for Salisbury were obtained from Broken Hill Associated Smelters at Port Pirie. Both plants used mineral sulphides (Yarraville iron pyrites and Port Pirie zinc concentrates) as a source of sulphur.

After glycerine, toluene, or cotton had been treated with the mixture of nitrating acids (sulphuric acid and nitric acid), an appreciable proportion of the nitric acid remained unused. At the same time the sulphuric acid, which was itself not consumed in the nitration process, became diluted with water formed as a result of the chemical interaction between nitric acid and the glycerine, toluene or cotton. Before the spent acids could be used over again they had to be separated and concentrated once more. Economy in the manufacture of explosives depended to a large extent on the efficiency of acid recovery, and special equipment was installed at each of the factories for this purpose. At all factories except Albion (where Pauling pots were used) concentration of sulphuric acid was carried out

[5] As mentioned earlier, 20 per cent oleum, the strength most used in the explosives industry, consisted of 20 parts of SO_3 and 80 parts of H_2SO_4, which was equivalent to 104.5 per cent H_2SO_4.

by the Bamag process, then new to Australia.[6] Spent sulphuric acid was not always reconcentrated. Salisbury, for example, returned large quantities of sulphuric acid which had been diluted in the course of nitration to the superphosphate works at Wallaroo.

Distillation columns used in the separation and concentration of the nitrating acids had to withstand their highly corrosive action. For this purpose few economically available materials were so effective as a cast iron containing about 0.5 per cent of carbon and 14.5 per cent of silicon. The difficult task of casting the distillation columns—30 per cent recovery of castings was considered good under some conditions—was carried out by the W. L. Allen Foundry Pty Ltd of Melbourne, and Quality Castings Pty Ltd of Sydney. Silicon-iron cracked easily under thermal or mechanical shock, but it was almost wholly impervious to the attack of nitric or sulphuric acid in any strength and at any temperature.

In pre-war days the soap and candle industries had no difficulty in supplying glycerine for making commercial and military explosives. The amount consumed was about 1,200 tons a year—1,000 for commercial and 200 for military explosives. The estimated requirements of glycerine for 1941 and 1942 were as shown in the table.

Estimated requirements of glycerine

	1941	1942
	tons	tons
Commercial explosives	1,200	1,200
Pharmaceutical and industrial uses . .	1,500	1,500
Military explosives	1,000	2,300
	3,700	5,000

The figures for 1942 exceeded the anticipated combined outputs of J. Kitchen and Sons Pty Ltd (Port Melbourne) and Lever Brothers Pty Ltd (Balmain, N.S.W.) and a number of smaller firms, by about 2,000 tons a year. Several courses of action were open to the authorities. Some saving could be expected from the introduction of rationing, but since there were many industrial uses for which there was no suitable substitute for glycerine not a great deal could be hoped for from this expedient. The output of glycerine was limited by two factors: the amount of soap made, which in turn depended on the availability of soda ash and caustic soda—both in short supply; and the capacity of the stills used in making glycerine of the purity needed for explosives.

Ordinary commercial glycerine consisted of about 80 per cent glycerine and 20 per cent water. Before it could be used for making explosives it was necessary to subject it to a double distillation. Glycerine could be obtained from fats without the necessity of making soap: tallow, for example, could be split into glycerine and fatty acids by treating it with

[6] The output of a Bamag concentrator was 19 to 20 tons of sulphuric acid a day when concentrating from 63 per cent to 96 per cent strength. The numbers of units installed at each factory were: Maribyrnong 2, Villawood 8, Salisbury 6, Ballarat 12, and Mulwala 8. Together their capacity was about 600 tons of sulphuric acid a day.

superheated steam. An annexe for working this process was built by J. Kitchen and Sons at their Melbourne works. The great drawback of the process was the problem of disposing of the fatty acids.

It was also possible to make glycerine by an altogether different process —by the fermentation of raw sugar in the presence of sodium sulphite. As an insurance against a possible shortage of glycerine, Leighton arranged with the Colonial Sugar Refining Company Ltd to develop this alternative source.[7] The fermentation process had been used on a large scale in Germany during the 1914-18 war and had been a major factor contributing to Germany's ability to continue waging that war. Developmental work progressed from laboratory scale to a pilot plant capable of an output of 3 tons of glycerine a week. A major difficulty which was overcome was to purify the product of fermentation so that it would pass the stringent specification for glycerine to be used in the explosives industry. The unit functioned quite successfully, but not for long. During 1942 an unexpected windfall in the shape of several thousand tons of glycerine was received from the United States, and so from 1943 onwards there was little anxiety about the supply of glycerine. In fact, stocks banked up, with the result that some thousands of tons were declared surplus.

The lack of a well-developed organic chemical industry, particularly of a section making dyestuffs which in other countries gave considerable support to the manufacture of explosives, was one of the handicaps suffered by Australia. Fortunately, as related in the chapter on chemical industry, one company that was beginning just before the war to exploit by-products of the coal gas industry, had the foresight to begin the large-scale alkylation of aniline to provide the starting materials dimethylaniline for the manufacture of tetryl and monoethylaniline for carbamite.

The development of Australian sources of cellulose to complete independence of oversea supplies was a first-rate achievement. For many years cotton was the traditional source of cellulose for making service propellents in the United Kingdom. About 1930 the Admiralty changed from cotton to wood paper in the manufacture of nitrocellulose for naval cordite in order to obtain a more uniform raw material and to open up a fresh source of cellulose. When the manufacture of naval cordite was first begun at Maribyrnong in 1935 paper wood cellulose was imported from the United Kingdom. This would have been an undesirable state of dependence in war, and in the late 1930's a joint program of investigational work was arranged between the Maribyrnong Explosives Factory, Australian Paper Manufacturers Ltd of Maryvale, Victoria, and the Munitions Supply Laboratories.

An essential requirement in cellulose for the manufacture of nitrocellulose was that it should be free from impurities which would affect the stability of the cordite. These impurities were chiefly lignin, oxycellulose and hydroxy-cellulose. Extensive experiments were carried out

[7] A modification of this process using molasses instead of sugar as the raw material was afterwards shown to be economical even in peace time.

on the purification of cellulose from hardwood (*Eucalyptus regnans*) but the difficulties proved so great that this raw material was abandoned in favour of softwood from *Pinus radiata,* large plantations of which were being grown in South Australia by the State Woods and Forests Department. By 1941 a stage had been reached at which the large-scale production of a suitable paper was possible. At first its use was confined to naval cordite (S.C.) but it was so obviously desirable to have only one raw material for all kinds of propellent that the experts set about achieving the widest use of the paper. Nitrocellulose for land-service propellents was nitrated to a higher degree (approximately 13 per cent of nitrogen) than that used for naval cordites (which were based on a nitrocellulose containing 12.2 per cent of nitrogen. The first step in extending the use of the paper was to develop a satisfactory method of nitrating to the higher degree. The first factory in the world to go into regular production of nitrocellulose of 12.9 plus or minus .15 per cent of nitrogen from wood cellulose by the "displacement" nitration process, was the Explosives Factory at Maribyrnong where its manufacture was begun in 1941 in order to provide nitrocellulose for Albion. A new factory at Ballarat followed some months later. By the middle of 1943 locally-produced paper-wood cellulose had displaced the imported paper altogether. Before the end of the war 10,000 tons had been produced.

One of the first matters taken up by the Director-General of Munitions after his appointment in June 1940 was the question of the second filling factory, about which he wrote to the Prime Minister as follows:

> An all-important requirement in munitions production is the filling of explosives into ammunition. Upon the figures of the advance copy of the Army Programme the cost of "filling" facilities will be £3,000,000 or more. But whatever the requirement, the capacity of the Maribyrnong Explosives Factory cannot be increased and a new factory must be erected elsewhere. The War Cabinet has decided that a site for No. 2 Filling Factory must be selected "away from the existing factories at Maribyrnong". As it is certain that a new filling factory must be erected somewhere, and quickly, the first step must be a decision as to site. As the persons to be employed, male and female, will be thousands probably, it will be obvious that only the vicinity of a large city will be suitable. Sydney and Adelaide suggest themselves immediately. . . .

The Premier of South Australia, Mr Playford,[8] was quick to point out the merits of the country near Adelaide as a site for the new factories. In addition to its strategic advantages, it offered a source of labour then largely untapped. The promise that the South Australian Government would cooperate by providing the land, an adequate water supply, bitumen roads, electric power, transport, and a means of disposing of the effluent, decided the issue. Within fifteen days of Lewis's letter to the Prime Minister a site covering approximately 4,000 acres of wheat land near the village of Salisbury, about 12 miles north of Adelaide, was chosen. There, in November 1940, was begun construction of the biggest project under-

[8] Hon Sir Thomas Playford, GCMG. (Served 1st AIF.) MHA, SA, since 1933; Premier since 1938. Of Adelaide; b. Norton's Summit, SA, 5 Jul 1896.

taken in South Australia up to that time, an aggregation of buildings that was ultimately to cost nearly £10,000,000 and to become the largest explosives factory in Australia. It was designed for making explosives as well as for filling and assembling ammunition. Through the energy and ability of Mr Haslam,[9] senior architect of the Department of the Interior, who was in charge of the construction works, and the cooperation of Mr Chapman,[1] Chief Engineer of the South Australian Railways, and their staffs, the buildings were erected and plant and machinery installed in record time. Chapman and his staff were responsible for the steam reticulation throughout the factories, except that for the detonator section which was installed by Stewarts and Lloyds Pty Ltd. Government departments, public bodies and private firms all played their part. The South Australian Government paid the cost of bringing water supplies, roads and railways to the boundaries of the magazine and factory areas.

The buildings were required to conform in design to well-established and stringent requirements. The architectural draughtsmen were in the beginning instructed in these requirements and worked under the close supervision of the technical staff of the Directorate of Explosives Supply. In equipping the factories the help of a large number of firms in other States was enlisted to provide air conditioning, refrigeration,[2] dust exhausts, storage tanks,[3] steam reticulation,[4] compressed air, rail tank cars,[5] vacuum exhausts, pure water supplies,[6] laboratories, workshops, power, fire-fighting and air-raid precaution equipment, and many others too numerous to specify.

On 14th November 1941, just a year after constructional work had begun and in half the estimated time, the great factory at Salisbury began to operate; by August 1942 it was making T.N.T., nitroglycerine, ammonium nitrate, and several initiators, but it was not until January 1943 that the factory as originally planned was complete.

The speedy and successful completion of Salisbury can be attributed to the versatility of, and the cooperation between, the engineers, architects and chemists, who in addition to their own duties were obliged to train and instruct their staffs in the special designs for explosives factories. Many of the technicians, of necessity recruited from technical colleges and schools, revealed such adaptability and skill as the work progressed, that they were later given executive positions in the plants.

In order to lighten the complex task of the Directorate of Explosives Supply in preparing drawings and specifications of plant and machinery,

[9] W. T. Haslam. (Served 1st AIF.) Superintending Architect, Dept of Interior, Canberra, 1936-39; Liaison Officer to Dept Defence 1939-41; Superintending Architect i/c Salisbury and Cheltenham Munitions Works, 1941-43; Dir of Works, S Aust, since 1946. B. Launceston, Tas, 2 Feb 1895.

[1] Lt-Col R. H. Chapman, CMG; ME. (Served with RE 1915-19.) Formerly Chief Engineer S Aust Railways; Railways Commissioner, SA, 1947-53; B. Adelaide, 5 Jan 1890. Died 10 May 1953.

[2] Messrs W. E. Bassett and Associates.

[3] Commonwealth Oil Refineries, Ltd.

[4] Messrs Julius, Poole and Gibson, Consulting Engineers.

[5] Vacuum Oil Co Pty Ltd.

[6] Fletcher Chemical Co (Aust) Pty Ltd, consultants on the demineralisation of water; Messrs Avery and Anderson; Messrs Sydney R. Bell and Associates; and Messrs Alexander A. Stewart and Co gave considerable help in the design of plant.

the authorities enlisted the aid of industry: the Shell Company to design buildings and plant for the T.N.T. unit, and I.C.I.A.N.Z. to supervise the erection of plants for making tetryl and ammonium nitrate. Over all these activities, and many others such as the layout of roads, railways, tramways, pipe lines, power lines and lines of communication, the Director-General of Works, Mr Hoy,[7] exercised a general supervision.

The task of filling and assembling ammunition was divided into sections according to the size and complexity of the components and the sensitivity and quantities of the explosives involved. One area at Salisbury was devoted to caps and detonators, where very small quantities of highly sensitive initiators such as fulminates and azides were pressed into small metal capsules. This area included facilities for making the initiators themselves since these were not easily transported with safety.

Another section handled small components: primers and fuses, of which caps and detonators were a part. Here primers were filled with gunpowder which, despite the fact that it was the first type of explosive invented, was still the best means of igniting propellents (cordites). Fuses were filled with tetryl. This section was therefore designed for the handling of relatively small quantities of explosives intermediate in sensitivity between detonators and propellents, and high explosives.

A third and much larger section was devoted to filling cartridge cases with propellent and fitting them with primers, and to filling shell bodies with high explosive, and assembling each to form a complete round of ammunition. It was necessary to conduct these operations in a separate area owing to the large quantities of explosive used in each filling operation, and in buildings set well apart from each other to reduce damage in the event of an accidental explosion.

The large area covered by the factory—between 7 and 8 square miles—is easily accounted for by the wide dispersal of the buildings. The British Home Office scale of distances between buildings, which was enforced in Australia at this time, determined the minimum distance (usually 50 to 100 yards) between two buildings containing explosives, the maximum quantities of explosives that should be carried in the buildings, and the minimum distances between these buildings and any others inside or outside the factory boundaries.

It is not easy to convey an idea of the full extent of the constructional work done at Salisbury. Altogether there were 1,595 buildings, linked to one another and to the outside world by

41 miles of road
34 miles of gritless cleanways[8]
13 miles of water mains
16 miles of sewers
150 miles of power lines (low tension)
6½ miles of underground telephone cables
27 miles of stormwater drains.

[7] C. A. Hoy. Works Dir for NSW 1935-38; Asst Dir-Gen of Works, and later Dir-Gen, Dept of Interior 1938-42; Asst Dir-Gen Allied Works Council 1942-45; Asst Dir-Gen Dept of Works and Housing 1945-51. B. Sydney, 19 Aug 1888.

[8] Gritless cleanways were pathways between buildings along which operatives or explosives passed. They were of special soft-surface construction, usually wood or gritless asphalt so that friction due to grit was reduced to a minimum. Special footwear containing no nails was used, and every effort was made to keep the cleanways free from dirt and grit.

There was a certain amount of uneasiness in administrative circles early in the war concerning the planning of the explosives and filling factories at Salisbury—a feeling that perhaps it was being done upon too grand a scale. Lewis, who had had no experience in the explosives industry, found it impossible to examine the overall planning with the attention that the magnitude of the task demanded, and he therefore asked Leighton to act as his consultant.

One of the central problems in extending the military explosives industry was that of providing staff for the new factories. It was here that the Maribyrnong Explosives Factory played a role for which it had long been planned. It possessed the only body of officers trained in the manufacture of military explosives and experienced in the techniques of filling ammunition. For the first half of the war it was the school to which staff recruited for the new factories was sent for training. Maribyrnong provided the managers for these factories and also the background of practical experience which enabled them to turn out products meeting the stringent requirements of Service specifications.

It had been the intention to make nitrocellulose at Salisbury but when investigation of the local water supply revealed a fairly high proportion of chloride ion, it was decided to move the nitrocellulose plant to another site. For this Ballarat was chosen. This decision was undoubtedly a sound one, although subsequent investigation showed that contrary to expectations water supplied to Salisbury from the Barossa reservoir made satisfactory nitrocellulose and quite stable cordite. The chloride ion content would, however, have led to a most serious corrosion problem had the original plan been adhered to, and for this reason alone the decision to build a factory at Ballarat was justified. At the time little was known in Australia of the reliability and efficiency of synthetic ion-exchanging resins which might have reduced the difficulties of setting up a new plant.

By the time work on the Ballarat factory was started in September 1940 the preliminary arrangements, such as the construction of a power transmission line from Melbourne and a new water main from the Ballarat reservoir, were well in hand. Since plants for making sulphuric and nitric acids would form important units of the new factory, arrangements were made with Australian Fertilisers Ltd of Port Kembla to secure the services of its works manager, Mr Craig,[9] in designing and constructing the new factory. Craig, who had had experience in the manufacture of nitrocellulose during the war of 1914-18 (he was one of the technical men who went to England under Leighton's scheme) gave considerable help to Donaldson and Topp in planning and constructing the new factory. Within a year the Ballarat factory, then the largest of its kind in Australia, began to supply both Albion and Salisbury with nitrocellulose, which for reasons of safety was transported in the wet form.

[9] R. J. Craig, MBE; BSc. Works Manager, Aust Fertilisers Ltd, Port Kembla, 1920-40 and 1944-50; on loan to Dept of Munitions 1940-44. B. Prahran, Vic, 17 Oct 1884.

Before proceeding with an account of the building of other new factories it will be convenient to pause briefly to consider some of the new types of manufacture that were undertaken. To a very large extent these were pioneered, developed and brought into production at Maribyrnong. The range and diversity of manufacture and filling at this factory was unapproached by any other factory in the British Commonwealth, for it made and filled almost every type of ammunition. It was the essence of the general plan of expansion that the new factories were equipped to produce large quantities of a few items.

The only initiator being made at Maribyrnong before the war was mercury fulminate. For some years I.C.I.A.N.Z. had made small quantities of lead azide for use in commercial detonators at its Deer Park Factory. Here the crystals of lead azide were coated with a thin layer of dextrin in order to improve safety in handling. Dextrinated lead azide did not perform satisfactorily in some military fuses. For military use the uncoated azide, which was naturally much more dangerous to handle, was preferred; its manufacture began at Maribyrnong early in 1941. Later, lead azide and lead styphnate were manufactured in large quantities at Salisbury. The production during the war of more than two tons and a half of initiatory explosives, usually in batches of a few pounds at a time, was not the least striking achievement of the explosives industry. Their manufacture and manipulation were the most dangerous operations carried out in *any* industry.

It was difficult to bring about the detonation of T.N.T. without the use of more sensitive explosives. The usual arrangement in shells, mines and bombs was for a small quantity of an initiating explosive (mercury fulminate, lead azide or lead styphnate) to be set off by the fuse mechanism. This small explosion was picked up by what was known as a "booster" type of explosive (usually tetryl), and it was the explosion of the booster that brought about the detonation of the main bursting charge of T.N.T. Tetryl had a ready response to small initiating impulses and built up to detonation more readily than T.N.T. The inclusion of a small quantity of tetryl between the detonator and the main charge permitted the use of a smaller detonator than would otherwise be required. High explosives designed for use in shells had of necessity to be so stable that they were relatively insensitive to shock or friction; a booster was therefore essential. For these reasons extension of the manufacture of tetryl was an important development. As it was already being produced by I.C.I.A.N.Z. for commercial explosives there was no difficulty in replicating plants at Salisbury and later at Villawood. It was made by nitrating dimethylaniline, demands for which had fortunately been anticipated by Timbrol Ltd.

In the course of trials carried out to determine the effectiveness of demolition charges, it was observed that poured T.N.T. detonated with tetryl was not developing its full power. Investigations made to discover the cause of this led to the devising of a greatly improved system for bringing about the detonation of cast T.N.T.—the form assumed by molten T.N.T. after it was poured into a shell or bomb. The effectiveness of

demolition charges was very considerably improved and the new system was successfully applied to a number of other projects, including anti-tank mines. Later it was demonstrated that shell could be improved in the same way but the war ended before the new system was adopted in service.

In order to eke out supplies of T.N.T. during the 1914-18 war the practice had been introduced of filling shells and bombs with intimate mixtures of T.N.T. and ammonium nitrate. Such mixtures, known as amatols, represented a great economy, for the cost of ammonium nitrate was, weight for weight, a good deal less than that of T.N.T. When efficiently detonated, amatol in a 40-to-60 mixture was only less violent than T.N.T. alone. One of the few innovations introduced at Salisbury was a plant for making ammonium nitrate by the double decomposition process. It was built by I.C.I.A.N.Z. with Mr Cresswick[1] of the Metropolitan Meat Industry Board acting as consultant. The plant was of unusual design and owing to lack of time was built without first having been tried out on a pilot scale. Very extensive phase-rule studies had been made on the ammonium sulphate-sodium nitrate system by Freeth[2] during the 1914-18 war and there was no lack of technical data. The plant gave a lot of trouble, much of which was attributed to impurities in the raw material used—ammonium sulphate from gas works. As soon as ammonium nitrate derived from the oxidation of ammonia became available the plant was closed down.

All the developments in the explosives industry described so far took place in South Australia and Victoria. The Director-General of Munitions had, however, not overlooked the necessity of building up a centre in New South Wales for manufacturing explosives and filling ammunition. Any such new development on the scale on which the explosives industry was then being expanded would require a large labour force which could be most readily obtained in the vicinity of a large city. The explosives industry was not one that lent itself to being split up into small factories distributed among a number of towns, and as there was no inland city with a big enough labour force the choice was narrowed down to sites on the vulnerable eastern seaboard. Some thought was given to the area inland from Newcastle, from which it was hoped to draw large numbers of women who could not, by reason of the heavy nature of the work, be employed in the surrounding coal and steel industries, but considerations of temperature turned the scale against any site much north of Sydney.

Sites near Sydney were the other alternative. At first a compromise was attempted by a proposal to use both areas (Newcastle and Sydney), but after all the relevant factors had been weighed—climate, labour supply, housing, water supply, disposal of effluent, proximity to residential areas,

[1] J. A. Cresswick. Chief Chemist Metropolitan Meat Industry Board 1922-48; Consultant on ammonium nitrate to Min of Munitions and Dept of Defence Production 1940-56. Of Sydney; b. Newcastle, NSW, 27 Dec 1888.

[2] F. A. Freeth, OBE; FRS, DSc. (Major, Cheshire Regt TA.) B. Birkenhead, Eng, 2 Jan 1884.

cost of land, access by road and rail, and liability to flooding—the Sydney district was chosen. The final plan approved by the War Cabinet on 11th July 1941 was to set up a filling factory at St Mary's, on the western railway line near Sydney, and an explosives factory at Villawood on the southern line. The St Mary's Filling Factory, second in size only to the filling section at Salisbury and comprising fuse, shell-filling and other sections, was practically completed by April 1943. On account of the humid summer weather much of the factory had to be air conditioned. The cost of this alone was £140,000.

A special section of St Mary's was given over to preparing pyrotechnic compositions and filling them into their containers: shells, smoke grenades, bombs, sea markers and the like. Pyrotechnic compositions, which as a rule consisted of oxidising agents (nitrates and chlorates) mixed with combustible substances (sulphur, antimony sulphide and powdered metals such as aluminium, zinc and magnesium) burned rapidly and almost explosively in the loose condition. For use in Service stores they were moulded in presses by the addition of a binding material which caused them to burn more regularly and controllably. The handling and filling of these compositions was attended with considerable fire hazard and for this reason a separate area was set aside for them.

At Villawood, some 22 miles distant by road, factories for making oleum and T.N.T. were built by Commonwealth Fertilisers Ltd and the Shell Company of Australia Ltd respectively, and all stages of production had been tried out by 1943. Trial production of tetryl was also achieved but it was never pushed beyond this stage. The amount of T.N.T. used in the early years of the war was far less than had been anticipated. The other explosives factories were always able to keep well ahead of demand, so Villawood was closed down.

Quite early in the war there were discussions on the possibility of manufacturing "flashless" propellents in Australia. In theory the choice lay between a single-based and a double-based propellent—between F.N.H. (flashless, non-hygroscopic) powder (essentially nitrocellulose) which was in general use in the United States, and naval cordite N.F.Q. (nitrocellulose-nitroglycerine) which was in general use in British Commonwealth countries. In the early days of the war, before intense aerial bombing attacks began, the real need was for flashless propellents for naval use. The American F.N.H. powder was not suitable for use in British naval guns so that the only choice was cordite N.F.Q., which depended for its manufacture on picrite (nitroguanidine). The chances of making picrite in Australia were small and there were at first no prospects of importing it. Nevertheless the Department of the Navy was anxious to see the manufacture of flashless propellents established in Australia and when it became possible to import picrite from Canada the decision was taken to go ahead with it. The investigational work, the pilot-scale manufacture, the acceptance of the product by the Naval Inspection Branch, and the making of the special cordite dies were all completed in less than six

months. Manufacture of flashless naval cordite (N.F.Q.) was well under way at Maribyrnong early in 1943.

In the meantime the possibility of making F.N.H. was being actively explored. An exchange of cables between the British War Office and the Australian Department of Munitions in September 1941 revived interest in the subject and led Donaldson to suggest that the cordite factory planned for Villawood should be abandoned in favour of one to make F.N.H. powder. On his advice a team of technical experts headed by Mr Stubbs,[3] Manager of the Villawood Factory, was sent to the United States, where it began investigations early in 1942. Meanwhile a site was chosen for the new factory. Proximity to ample supplies of water and power and ready accessibility to rail transport were among the main considerations which led to the selection of Mulwala, a town on the Murray River in New South Wales. On the basis of the information received from the United States, the Directorate of Explosives Supply began to plan the layout of the factory and the design of the buildings.

F.N.H. powder was unfortunately neither flashless (except in a few low-performance guns) nor completely non-hygroscopic. Its real advantages were that it did not require nitroglycerine, and that it was a freely flowing granular powder which lent itself to the automatic filling of cartridge cases. Although it was by no means the ideal propellent, being much less successful than picrite propellents in reducing erosion, its advantages outweighed these shortcomings and negotiations were put in hand under the Lend-Lease Agreement to acquire from Messrs E. I. Dupont de Nemours and Co a complete packaged manufacturing unit from the United States. The Directorate of Explosives Supply had merely to build a structure to house the unit, provide an acid plant, and arrange with the Victorian Government for supplies of electrical power and linking up with the State railway system. In his reminiscences of this period Sir John Jensen said: "This was the only Lend-Lease request ever to be approved without great lapse of time and much travail in argument." United States authorities gave Australia priority over their own works at Gopher, and plant began to arrive in Australia in the middle of 1942. No doubt the hope that they would be able to obtain ammunition from this source for use in the South-West Pacific Area had something to do with the speed with which the request was granted.

Unfortunately the speed with which the equipment was despatched from America was not matched by that of the factory builders. The Allied Works Council had promised to complete the buildings within six months, but they actually took more than eighteen months to finish the work. This was one of the less creditable pages in the story of the wartime explosives industry.[4] Strong representations from the Director-General of Munitions were necessary before the constructional works at Mulwala

[3] C. W. O. Stubbs, BSc. Senior chemist, Explosives Factory, Maribyrnong, to 1941, Asst Manager 1941; Manager Villawood Explosives Factory 1941-42, and Mulwala Factory 1942-51. Of Melbourne; b. Sandhurst, Vic, 30 Mar 1891.

[4] Directorate of Explosives Supply, Report No. 120, 18 Jan 1943.

could be got fully under way. Eventually a camp accommodating 3,000 men—the largest camp of its kind set up in Australia during the war—was erected and the buildings and works, costing nearly £2,000,000, were completed. The first trial runs on single units of the plant were made at the end of 1943, and in February 1944 the first samples of powder for filling cannon ammunition were submitted to the Inspection Branch. Production reached its peak about the middle of 1944.

While awaiting the arrival of plant from the United States the Munitions Department had asked Australian Paper Manufacturers Ltd to see whether it could make a still more highly purified form of cellulose, known as "alpha-cellulose board"—board, because this was the final form it assumed. Alpha-cellulose board was one of the principal raw materials that would be required for Mulwala. The use of wood pulp in making nitrocellulose had been recently developed in the United States and specifications for alpha-cellulose board for this purpose were most exacting. Although the degree of chemical purity required was considerably higher than had so far been attained by Australian Paper Manufacturers, their experience with paper-wood cellulose afforded some grounds for optimism. The company had, in point of fact, been experimenting since 1939 with the production of a high-purity alpha cellulose for Messrs Johnson and Johnson, makers of cotton wool and surgical dressings. Having failed to satisfy the requirements of a cellulose for these applications by using hardwood pulp as a source, the company turned its attention to *Pinus radiata,* as they had been forced to do in making paper wood cellulose for cordite S.C. By employing a cold refining process it was found practicable to make pulps with 92 to 93 per cent of alpha cellulose with a high degree of whiteness, but this was still not good enough to meet the requirements of the American specification. Mulwala was obliged to rely on imported alpha-cellulose board for its war production.[5]

Though completed late in the war, the building of the Mulwala factory was fully justified. One of the hopes of those who planned the factory was that it would survive the war period to become a permanent addition to the scheme for decentralising the manufacture of military explosives. This was indeed what it became.

This completes the survey of the growth of the explosives and filling factories during the war; it does not cover the network of annexes and factories in which the metal components of ammunition were made. Before the end of the war over 3,000 buildings, which with magazine areas occupied an area of more than 11,000 acres, were erected and operated, at a cost of approximately £22,000,000, for the manufacture of ammunition and explosives. Their distribution among the States is shown in the accompanying table. At the peak of their activities nearly 20,000 men and women were employed in the explosives and filling factories.

[5] Manufacture of a satisfactory material was achieved some years after the war.

EXPLOSIVES FACTORIES IN AUSTRALIA 1939-45

(Showing principal manufactures only)

SOUTH AUSTRALIA

SALISBURY:
- Explosives:
  - Nitroglycerine
  - Cordite
  - T.N.T.
  - Tetryl
  - Lead azide
  - Lead styphnate
  - Mercury fulminate
- Filling:
  - Shells
  - Mortar Bombs
  - Detonators
  - Percussion caps
  - Cartridges
  - Fuses
  - Primers
  - Depth Charges
- Nitric Acid
- Ammonium Nitrate

VICTORIA

MARIBYRNONG:
- Explosives:
  - Nitroglycerine
  - Cordite
  - Nitrocellulose
  - T.N.T.
  - Mercury fulminate
  - Lead azide
- Filling:
  - Shells
  - A/C Bombs
  - Mortar Bombs
  - Pyrotechnics
  - Cartridges
  - Grenades
  - Fuses
  - Detonators
  - Primers
  - Depth Charges
  - Naval Mines
  - Demolition Charges
- Nitric acid

DEER PARK:
- Explosives:
  - Nitroglycerine
  - Gunpowders
  - Blasting Explosives
  - Lead azide
  - Tetryl
  - Lead styphnate

ALBION:
- Nitroglycerine
- Cordite
- T.N.T.
- Carbamite
- Ammonia
- Nitric Acid

BALLARAT:
- Gun paper
- Oleum
- Nitric acid
- Ammonia
- Ammonium Nitrate

NEW SOUTH WALES

VILLAWOOD:
- T.N.T.
- Tetryl
- Ammonia
- Nitric acid

ST MARY'S:
- Filling:
  - Mortar Bombs
  - Cartridges
  - Shells
  - Pyrotechnics

MULWALA:
- Nitrocellulose powders
- Nitrocellulose
- Ammonia
- Nitric acid

The great majority of the 20,000 workers recruited for the explosives factories were entirely new to such work and had to be trained by experienced workers drawn almost entirely from the government factory at Maribyrnong. One of the considerations uppermost in the minds of those directing the factories was that of operational safety. In anticipation of rapid expansion in the manufacture of explosives, the Minister for Supply,

Mr Casey, approved on 2nd October 1939 the appointment of a committee known as the Operational Safety Committee. When urging the need for such a body, Leighton had written:

> We have talked on many occasions about the need for setting up within the government factories organisation, means for securing the safety of operatives, and what is of paramount importance at the present time—the safety of factories and their continuance in operation. . . . It is unlikely in my experience that we shall continue to enjoy freedom from accidents, but it is specially necessary in our particular situation that we should not neglect precautions calculated to avoid them. In England during the last war we had accidents without number, many of them serious but none that crippled production, for the reason that in England then we usually had ten or so separate points of production. In Australia, with few exceptions, the position is that we have one point of production and therefore the need for care of what we have needs emphasising.
>
> The position of the mechanical factories for making metal components of ammunition is relatively safe and although it should be examined as soon as the opportunity offers, that of explosives and related factories should, I think, receive early attention.

The committee was charged with the duty of periodically visiting the Government Explosives Factory, Maribyrnong, and reporting on safety measures, which were to be based on those obtaining in England during the war of 1914-18.[6] The responsibilities and functions of this advisory committee were enlarged as the war progressed. Thus, once the building of the new factories was begun, the scope of the Operational Safety Committee was enlarged "to supervise the production of Service explosives in regard to public safety", which meant in effect that it examined and reported on plans of proposed new installations, factory layouts and manufacturing processes.

Among the safety precautions taken in factories which handled sensitive explosive compositions were the following: metallic articles which could cause a spark were excluded; smoking and even carrying of matches or tobacco were totally prohibited; operatives were not permitted to wear watches; clothing was held by tapes, and the use of buttons was avoided; special shoes were provided in which the soles were held together with wooden pegs instead of the usual metal brads. "Cleanways" were made of wood or asphalt and regularly hosed. Concrete in paths was often filled with gypsum in order to minimise the risk of sparks.

Just as dangerous as sparks caused by friction were those due to the building up of electrostatic charges, and many precautions were taken to minimise the danger from this source. The more sensitive the explosive the greater the precautions. In the building where mercury fulminate, lead azide and lead styphnate were handled the following stringent precautions were adopted: the door was fitted with a heavy brass handle, which was thoroughly earthed; it closed automatically and was held in position against a powerful non-sparking phosphor-bronze spring; before entering, one

[6] At the time of its first meeting on 7 Aug 1940 the members of the committee were: A. E. Leighton (Consultant on Explosives, Dept of Supply), Chairman; K. B. Straw (Chief Inspector of Explosives for Vic), Executive Member; A. A. Topp (Manager of Explosives Factory), Member; J. Wood (ICIANZ), Member; S. J. Proctor, Secretary. The following were appointed after the first meeting: A. G. Hall; J. M. Grist (ICIANZ); J. T. McCormick (Superintendent, Supply Labs.).

was required to whistle and wait for an answer in order to avoid startling the operator inside. The floor and working bench were covered with conducting rubber, and the pot containing several ounces of explosive was also of conducting rubber; the shoes provided were soled with rubber. All these precautions were essential, especially at Salisbury where the dry summer atmosphere favoured the building up of electrostatic charges.

Danger from fire and explosions, however, constituted a less important threat to the morale of workers in the industry than did hazards to health arising from the highly toxic nature of many of the substances handled.

The handling of sulphuric acid (from 63 per cent to 104.5 per cent strength) at temperatures ranging from cold to boiling point (315 degrees centigrade), of nitric acid (from very weak up to 98 per cent strength), also at temperatures ranging from cold to very hot, and of the mixed acids used for nitration, all constituted serious hazards. There were many cases of mild gassing by sulphur dioxide and oxides of nitrogen; gas masks were often used, though they were not very effective against these particular gases.

It was well known that nitroglycerine when absorbed by the body either through the skin or by inhaling the vapour, depressed blood pressure and caused violent headache which aspirin and other analgesics did little to relieve. Some men seemed either to be naturally unaffected by the nitroglycerine or to develop a tolerance to it, and these were the only people who could work in a nitroglycerine plant without acute discomfort. Paradoxically absenteeism was lower among men in the nitroglycerine section at Salisbury than among those working in less hazardous sections of the factory. One suggestion was that the men who did this job successfully had been picked out from a much larger number and were unusually strong. A more convincing explanation was that a camaraderie grew up among the men engaged in this work and it became a point of honour not to let the other fellows down. Perhaps both factors contributed.

Many individuals were prone to dermatitis caused by T.N.T. and tetryl. Methods of prevention developed in consultation with the Department of Health did much to reduce the hazard. When dermatitis persisted whatever the conditions of working, the only remedy was to transfer the victim to another section. The incidence of dermatitis was highest among workers handling tetryl, particularly in the fuse-filling and shell-filling sections where tetryl pellets or tetryl exploders were made.[7] Machines making these components created a dust which, in spite of the ventilating systems for extracting fume and dust from the air, would settle on the arms, faces and necks of the girls who did this work. Unless the dust was removed efficiently with special soaps, clothing completely changed at the end of a working section, and showers frequently taken, the incidence of dermatitis was high—often high enough to seriously impede the output of explosives. No completely satisfactory answer to the problem was ever found.

[7] Exploders were made by putting tetryl into bags about an inch in diameter and three inches long, made of heavy woollen cloth.

A greater menace to health than the dermatitis was poisoning by T.N.T., which was readily absorbed by the human body; it attacked the liver, causing serious and sometimes fatal illness. Fortunately, simple but effective tests had been devised which enabled the progress of T.N.T. absorption to be followed and which indicated when a dangerous level had been reached. They were carried out at frequent intervals on all workers handling T.N.T. Transfer to other work not involving T.N.T. usually eliminated the poison and no permanent harm was done. During the hot, humid months when excessive sweating increased the rate of absorption of T.N.T., the number of workers declared by the medical officer as unfit for duty became a serious embarrassment and led to great difficulty in maintaining production. At the worst time of the year the turnover of skilled workers in the T.N.T. filling sections at Maribyrnong and Salisbury rose to as high as 10 per cent per month and the finding of enough new workers and of employment for those declared unfit for work with T.N.T. was a major problem.

The years of careful study and building up of safety consciousness at Maribyrnong paid dividends when the new factories came into being. Their freedom from serious accident, the possibility of which was never entirely absent from the explosives industry, reflected great credit on the factory managers and on those who had laid the foundations of sound methods of training, leaders of the Australian industry from its earliest days onwards—Leighton, Brodribb, Topp and Hall.[8]

Up to the end of the war no single accident causing fire or explosion was responsible for more than two deaths. In other words, there were no really severe accidents; that is, severe as judged in the explosives industry. Safety was largely a matter of paying attention to a great number of minor details and it required much tact and patience to bring home the importance of these apparently trifling and sometimes irksome details to the new and enthusiastic recruit.

The accompanying table summarises the accidents reported in Australia over the years 1939-45.

Group	Fatal accidents			Accidents causing injury but no fatality		Accidents not causing injury	
	No. of fatal accidents	No. of persons killed	No. of persons injured	No. of accidents	No. of persons injured	No. of accidents	Total No. of accidents
Explosives manufacture	6	6	11	10	11	57	73
Filling stores	3	4	4	51	67	82	136
Experimental	2	2	1	11	17	4	17
TOTAL	11	12	16	72	95	143	226

As the scale of manufacture increased it was inevitable that large quantities of explosives accumulated, often in the neighbourhood of wharves

[8] A. G. Hall. Assistant Manager, Explosives Factory, Maribyrnong, to 1940, Manager 1940-50. Of Melbourne; b. Elmore, Vic, 3 Oct 1883.

and in closely settled areas. The stores constituted a far graver menace to the community than did the factories. Transporting large quantities of explosives by sea and land also had its share of danger. For land transport special rail and motor vehicles were designed. On all matters relating to the packing, storing and transport of explosives the Operational Safety Committee gave invaluable advice and did much to reduce accidents to a negligible proportion. Its advice took the form of a booklet, *Information for the Guidance of Officers Engaged on the Transport of Service Explosives under War-time Conditions.* When it appeared that Australia might be invaded by the Japanese, the committee advised on methods of destroying stocks of explosives and armament chemicals without endangering the civil population.

As the constructional activities of the Directorate of Explosives Supply began to draw to an end, attention was diverted to problems of the coordination and efficiency of technical processes in the newly established factories. In a project of the magnitude of explosives supply it was obviously not enough to produce the required amounts of explosives irrespective of costs and technical efficiency. In May 1943 Donaldson put forward, with the approval of the Director-General of Munitions and of the Factory Board, an Efficiency Scheme, which followed closely a similar scheme that had been worked out in Britain during the first world war.[9] Donaldson's experience in the control of a large number of factories in England after that war had convinced him that it was a good practice to provide at each factory engineers to deal with maintenance and with work involving only a small capital expenditure, and to hold in a central organisation an experienced body of men capable of handling the major projects. He therefore built up a central engineering team which had, collectively, a detailed knowledge of the plant and machinery used in the factories, and made it part of a central Efficiency Section. This section was housed in the Melbourne headquarters of the directorate and concerned itself with and advised upon such matters as:

1. Proposals for development of improved practices in explosives technique; for the replacement of obsolescent plant, standardisation and coordination of practices in the different factories.
2. Efficient use of materials and labour.
3. Liaison with government explosives establishments in the United Kingdom, Canada and the United States in order to obtain information on the latest developments in these countries. Such information was circulated among the factories from time to time.
4. Standardisation of measures against health hazards, safety rules and general welfare practice.

The Efficiency Section settled priorities for materials, such as silicon-iron, which were in general use in all the factories, and rationed scientific instruments and special equipment in short supply. In an effort to estab-

[9] *Second Report on Costs and Efficiencies in His Majesty's Explosives Factories Controlled by the Factories Branch of the Explosives Supply, London.* HM Stationery Office (1918).

lish basic costs upon which comparisons might be made of the efficiency of factories producing the same chemicals, statistical studies were made of labour costs and of the consumption of materials. Gross differences in the costs of producing a given chemical were known to exist between the factories but it was difficult to decide how much of this was due to special local conditions and how much to real differences in efficiency. Figures were compiled by Mr Hedding[1] giving comparisons in considerable detail between English and Australian performances for various stages of filling practice. In most instances investigated the comparison was unfavourable to Australia, but it should not be inferred from this that it was true of the Australian factories in general.

There can be no doubt, however, of the general benefits accruing from Donaldson's scheme, since it did focus attention on the need for efficiency and economy. Under the scheme, for example, statistical methods of quality control were introduced. Their use in the explosives factories appears to have been one of the first instances of their extensive application in Australia. A quality-control section was later set up under Mr Wallace,[2] a chemist with considerable experience in the use of statistics. Liaison officers were appointed in each of the explosives factories and periodic visits were made by officers of the central section to explain the principles of quality control and later to give assistance in the application of the methods to specific phases of manufacturing activity.

At least a dozen different processes were studied, ranging from filling shells and bombs to assembling fuses and pressing pellets, and some remarkable economies and improvements in manufacture were effected. For instance, the number of rejects in the filling of naval shells was reduced from 6 per cent to less than 0.1 per cent; the rejection of detonators from 30 to 0.1 per cent, and of caps from 14 to 1 per cent.

Investigations and testing of explosives were carried out in the Explosives and Ammunition Section of the Munitions Supply Laboratories, which grew from a group of 12 experienced chemists into an extensive organisation with branch laboratories in each of the explosives factories and a staff which at its peak numbered 110.[3] Inspection and routine testing to see that Service specifications were being properly met formed the greater part of the work carried out in each of the branch laboratories; only at Maribyrnong itself was any extensive investigational work done, and there fourteen out of the fifty-four scientists were so engaged. An idea of the extent of the testing activities of the explosives laboratories may be gathered from the fact that during the years 1940-45 about 250,000 samples were handled.

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[1] W. A. Hedding. (Served 1st AIF.) Chemist, then Assistant Manager, Explosives Factory, Maribyrnong. B. Melbourne, 17 Apr 1897.

[2] W. N. W. Wallace, BSc. Chief Chemist, Lysaght Bros, to 1941; Head of Laboratories, Explosives Factory, Ballarat 1941-43; Head of Quality Control Dept, Dir of Explosives Supply, 1943-45; Chief Chemist, ICIANZ Biologicals Factory, Villawood, since 1945. Of Sydney; b. Sydney, 8 Nov 1908.

[3] The factories also had their own laboratories for developmental work and process control.

A great deal of the investigational work at the Munitions Supply Laboratories was of the *ad hoc* kind, designed to give quick answers to questions concerning the functioning and safe handling of explosives. Manufacturing problems were referred to this section, and also problems dealing with the causes of the defective functioning of explosives. One of its most dangerous but vitally important tasks was to make a critical study of captured enemy ammunition. There was little opportunity for fundamental research on explosives, and indeed the laboratories had not been intended for that purpose. For work of this kind we must turn to the C.S.I.R.

The initiation and growth of explosions. From the scientific viewpoint one of the most interesting wartime developments relating to explosives was the fundamental work on the initiation and growth of explosions carried out by Dr Bowden and his collaborators in the Lubricants and Bearing Section of the C.S.I.R. In spite of all the investigations previously made on nitroglycerine and the vast quantities of it that had been manufactured and used since Nobel first began production in 1863, the behaviour of nitroglycerine towards impact was by no means well understood even as late as 1942. Unexplained explosions at the Deer Park factory of I.C.I.A.N.Z. suggested that the sensitivity of nitroglycerine under certain conditions might be much greater than was generally supposed. It was known that liquid nitroglycerine and other similar substances could be detonated by impact if it was sufficiently violent, but little was known of the mechanism by which the mechanical energy of the blow initiated the explosive reaction. Here, then, was a problem not only of great theoretical interest but of the highest practical importance in the manufacture and safe handling of explosives.

Bowden was a first-class experimenter with a knack of devising relatively simple experiments to obtain the answers to important problems. His interests at that time lay in the study of friction (and in tribophysics generally) and since it was believed that friction had much to do with the initiation of explosions (though this appeared to be more important in regard to solids) it was not surprising that when I.C.I.A.N.Z. invited him to study the problem of the origin of unexplained explosions in nitroglycerine at Deer Park, he took up the work with great enthusiasm.[4]

Quantitative studies of detonation caused by impact were not easy to make. Some had already been carried out in England and in Germany. The usual method was to place a small amount of the explosive on a flat metal plate (anvil) and then to strike it with a flat-faced weight or hammer. The sensitivity of the explosive was expressed in terms of the potential energy of the hammer necessary to cause detonation. With mercury fulminate the limiting potential energy for regular detonation was calculated statistically to be about 500 gram centimetres (that of a 100-gram weight dropped from a height of 5 centimetres, for example).

[4] F. P. Bowden, F. Eirich, A. E. Ferguson and A. Yoffe, "The Detonation of Nitroglycerine by Impact", Bulletin 167, C.S.I.R., Melbourne, 1943.
F. P. Bowden, F. Eirich, M. F. R. Mulcahy, R. G. Vines and A. Yoffe, "Detonation of High Explosives by Impact", Bulletin 173, C.S.I.R., Melbourne, 1943.

The values found for nitroglycerine by earlier investigators differed very widely from one another but were in general very much greater (from 1,000 to 14,000 gram centimetres).

The divergence in values obtained for nitroglycerine clearly meant that the phenomenon was not thoroughly understood. Obviously there were important factors not recognised by the experimenters and therefore not properly controlled. With the help of Dr Finn[5] of I.C.I.A.N.Z., whose experience in the manufacture and handling of commercial explosives was of great value in the early stages of the work, Bowden and his collaborators began a systematic study of the detonation of nitroglycerine under various conditions of impact. Having recently developed the "hot spot" theory of friction between moving surfaces, he attempted to apply it to explain the detonation of nitroglycerine by impact. According to this theory, during the sliding of one solid over another the points of contact[6] between highly polished surfaces were at a sufficiently high temperature to cause the solid in this region to melt and the two points momentarily to weld together. The frictional force arose mainly from the making and breaking of these minute, temporary welds. Bowden failed, as he expected he would, on the basis of this theory of friction, to detonate nitroglycerine by the impact of surfaces of solids whose melting point was below 185 degrees centigrade—the temperature required for the thermal initiation of an explosion of nitroglycerine. But when, keeping all other conditions constant, he also failed to detonate nitroglycerine by fairly violent impact of surfaces of solids of melting point far above 185 degrees centigrade, he was forced to abandon this restricted form of the "hot spot" theory.

There is no space to describe the many ingenious and systematic experiments that were made in search of an alternative theory. Suffice it to say that from the mass of results two discoveries stood out from the rest. The first was that the sensitivity of nitroglycerine to impact between flat metal surfaces was markedly increased if the liquid contained small bubbles of air. Simple calculations showed that the heating of this gas caused by sudden, that is, adiabatic, compression could be quite high and well above the ignition point of the explosive. This heating was therefore sufficient to initiate the explosion.

The second discovery, which in some ways was more impressive than the first, though for a time certainly more puzzling, was known as the "cavity effect". Flat-nosed bullets attached to a pendulum hammer and allowed to fall and strike a film of nitroglycerine, failed to produce any detonation. On the other hand, when a bullet with a small circular cavity in its nose was made to strike the nitroglycerine in such a way that the complete rim of the cavity made simultaneous contact with the liquid, detonation occurred with astonishingly small energy. A bullet weighing 43 grams and falling 1.5 centimetres (potential energy 64.5 gram centimetres)

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[5] A. E. Finn, DPh. Research Chemist, Nobel's Explosives Ltd, Ardeer, Scotland, 1937-38; Superintendent Explosives, ICIANZ, Deer Park, 1939. B. Perth, WA, 9 Nov 1911.

[6] Only a small proportion of the areas of two highly polished surfaces make contact when the two are brought together.

was sufficient to cause a detonation. This was very much lower than the figure given by any previous investigator (the lowest quoted above was 1,000 gram centimetres) and was even lower than that usually given for an initiatory explosive such as mercury fulminate. In later experiments the energy required was occasionally as little as 20 gram centimetres. Under these conditions the velocity of the bullet, which was made part of a pendulum system, was very low and its impact with the anvil corresponded more to a gentle tap than a blow.

The obvious explanation of the cavity effect was that it was due to the adiabatic compression of air included within the cavity of the striker. However, this seemed to be completely ruled out by an experiment which showed that increased sensitivity could be obtained even when the cavity of the striker was carefully filled with liquid nitroglycerine before it was allowed to strike the anvil covered with the same liquid. The investigators believed that under these conditions no air was present and for a time they were completely baffled by the "cavity effect". After they had explored other possible explanations, all of which proved inadequate, they were forced to return to a more critical test of the possibility of adiabatic compression. On making a microscopic examination of the fluid in the cavity of the striker they discovered that, no matter how carefully it had been filled with nitroglycerine, at least one exceedingly small bubble was invariably present. Sudden compression of these bubbles which, as a rule, were less than one ten-millionth of a cubic centimetre in volume, was sufficient to initiate an explosion. Bubbles of this size were, of course, impossible to see with the naked eye.

Unravelling of the seeming mystery of the "cavity effect" provided striking confirmation of the importance of the role of adiabatic compression of air bubbles in initiating explosions. The scientific significance of this work was that it paved the way to a much greater understanding of the initiation and propagation of explosions in general. Bowden followed up this work at Cambridge after the war, and reached the general conclusion that initiation of explosions by impact and by friction is usually of thermal origin. His findings were embodied in a monograph which appeared some years later.[7]

On the practical side their application to safety measures, especially in the handling of liquid explosives such as nitroglycerine, was obvious. From a search through the official history of accidents, it became evident that the adiabatic effect offered a possible explanation of many otherwise mysterious explosions. Though Bowden's work does not appear to have had much influence on practice in the government explosives factories in Australia, more attention was paid to it in England. For example, members of the Cambridge School who later joined Imperial Chemical Industries Ltd assisted in applying some of the results very effectively at the Ardeer factory.

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[7] F. P. Bowden and A. D. Yoffe, *The Initiation and Growth of Explosions in Liquids and Gases*, Cambridge University Press (1952).

While Bowden and his colleagues were continuing their early studies on the origins of explosions in nitroglycerine at the University of Melbourne, Mr Bird[8] of the Maribyrnong Supply Laboratories followed, quite independently, a different line. He conceived the idea of initiating explosions by placing the explosive in a cylinder closed with a tightly fitting piston. Solid as well as liquid explosives could be detonated by suddenly compressing the air within the cylinder.

These conditions were slightly different from those used in Bowden's experiments: the air was in external contact with the explosives whereas in Bowden's experiments the air was trapped within the explosive. Nevertheless, the mechanism by which the explosion was initiated was the same —namely by the heat developed as a result of the adiabatic compression of air. Bird had in fact rediscovered a phenomenon that had been discovered independently by English, French and Italian scientists soon after the 1914-18 war. Italian scientists had attempted to apply the principle to the manufacture of fuses without detonants but had failed to obtain satisfactory build-up to detonation. Unaware of this earlier work, Bird also attempted to make "detonantless" fuses. After many trials he finally succeeded, in July 1944, in detonating a high explosive shell with a simple detonantless compression fuse, an achievement which suggested that it might be possible to devise a generally workable fuse along these lines, and thus do away with hazardous initiating explosives such as mercury fulminate and lead azide and all the complicated safety devices which had to be used with them.

[8] L. H. Bird. Chemist, Explosives and Ammunition Research Section, MSL, 1941-45; Chemist, Wheat Research Institute, Christchurch, NZ, 1945-55. Of Christchurch; b. Waimate, NZ, 29 Jun 1914.

CHAPTER 17

CHEMICAL WARFARE

FEW new weapons introduced during the war of 1914-18 created a deeper impression, on military and civilian minds alike, than the use of toxic gases. Consequently the subject of chemical warfare occupied a prominent place in the plans of most defence organisations during the period between the wars. To this the Australian Department of Defence was no exception. In 1924 it set up the Chemical Warfare Board,[1] which was closely modelled on the corresponding organisation in the United Kingdom. Since it was evident that so far as offensive chemical warfare was concerned it would be many years before Australian chemical industry, more especially the chlorine industry which was essential for the manufacture of mustard gas and lewisite, could reach a scale of production of any significance, the board concentrated on the problem of defence —of providing the soldier with efficient equipment to prevent him from becoming a casualty in chemical warfare. It sent the Secretary, Mr Weldon,[2] to Porton, England, in 1927 to study the technique of manufacturing respirators and the design of laboratories suitable for the inspection and testing of respirators. From a technical point of view the performance specification of a service respirator was most exacting and required an elaborate system of scientific control in the production and assembly of component parts.

Shortly after Weldon returned to Australia in 1929, the Munitions Supply Laboratories put up a special, isolated building at Maribyrnong for work on toxic gases and anti-gas equipment. There was some objection at the time to chemical warfare's being given official recognition, the view being taken that mention of it should be excluded from official documents. Since, in fact, the board was concerned mainly with the defensive aspects, no objections were raised when the more appropriate titles of Chemical Defence Board and Chemical Defence Laboratory were adopted. During the next few years the principal aim was to make Australia self-sufficient in the supply and maintenance of respirators and protective clothing (of the impervious type) for the armed services, but it was some years before this aim was realised: requirements for respirators, for example, were so small that it was not considered worth while asking local industry to manufacture the component parts. In the meantime the laboratories at Maribyrnong confined themselves to assembling respirators from imported components. Dependence on outside supplies was slowly diminished, and by 1937 local industry produced all except two of the components for the General Service Respirator Mark IV. The manufacture of laminated safety glass in the following year left activated carbon as the only item that still had to be imported.

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[1] Under the chairmanship of Mr A. E. Leighton, Controller-General of Munitions.

[2] P. R. Weldon. (Served 1st AIF.) Analyst; of Essendon, Vic; b. Brighton, Vic, 26 Mar 1892.

In due course, in 1936, the Munitions Supply Laboratories took the logical step of building a separate assembly factory adjacent to the Chemical Defence Laboratory. Contracts were let to commercial firms for the supply of component parts. The technical staff of the laboratory directed the operations of assembly, helped contractors to meet the requirements of the specifications, and carried out performance tests on the finished respirators.

The Munich crisis greatly accelerated the output of service respirators, the drafting of regulations for air raid precautions, and the training of key civilian personnel in anti-gas precautions. The Defence Department made arrangements with Imperial Chemical Industries of Australia and New Zealand Ltd for the production of bleaching powder, the most effective of relatively cheap and easily produced substances for decontaminating areas affected with mustard gas.

In the early months of the war the output of respirators was barely sufficient for the armed forces. There were none to spare for export to other Commonwealth countries, and very little had been done to provide respirators for the civilian population. By the end of 1941, however, about 750,000 had been supplied to the Services and the Department of Home Security.

To be fully protective, a respirator had to be able to prevent toxic airborne particles and droplets,[3] as well as toxic gases, from entering the lungs of the wearer. The type E container used in the general service respirator relied on a fibrous filter of feather-down to remove particles or droplets of toxic agents. When supplies of feather-down, customarily imported from China, became uncertain, local materials such as mutton-bird feather-down, which contained a larger proportion of feathers, were accepted as substitutes in order to eke out supplies. The discovery that stocks of feather-down had become infested with case-making clothes moths caused considerable doubt and alarm about the condition of down in the containers already issued. Fortunately the lampblack with which the down was impregnated in the normal preparation of the filter proved sufficient to kill the larvae of the moth.

Only by the closest attention to detail was it possible to attain the degree of protection specified for the general service respirator by using feather-down. When, therefore, a more efficacious filter consisting of a pad of 20 per cent asbestos and 80 per cent merino wool was developed in the United Kingdom, the Chemical Defence Board decided to abandon the feather-down filter in its favour. The technique of making the filter had been studied by Mr A. J. Roennfeldt, Senior Chemist of the Chemical Defence Laboratory, during a visit to Britain in 1941, and on his return there was little difficulty in putting it into practice at an annexe operated by Slazengers Ltd, Sydney.

[3] Some toxic chemical warfare agents were not gases at ordinary temperatures. For example, some arsenical "gases" were in the form of liquids which could be dispersed as particulate clouds with droplets ranging in size from 0.1 to 10 microns by spraying or by ejection from a high-explosive shell.

Charcoal for respirators was originally imported from Britain, Canada or India, a practice that continued until the end of 1941. The first move towards self-sufficiency was made when the Colonial Sugar Refining Company, presumably because of its experience in the manufacture of animal charcoal for the clarification of sugar solutions, was asked to consider the possibility of manufacturing activated nut charcoal. Although most charcoals, whatever their origin, had the power of adsorbing gases, none was so suitable for this purpose as that derived from coconut shell. Merely charring the coconut shell was, however, not enough; to be fully effective as an adsorbent for gases the charred shell had to be activated. Activation consisted of heating the charcoal to about 1,000 degrees centigrade in the presence of steam, which caused it to lose about 60 per cent of its weight without undergoing any change in superficial appearance. The change was in its sub-microscopic structure: numerous microscopic and sub-microscopic channels and pores, cleared of resinous and other material, were now accessible to gases which became adsorbed on the walls of these voids.

A satisfactory commercial process for the activation of charcoal had been patented and operated for many years by Messrs Sutcliffe Speakman at Leigh, in England, and it was to this firm that the Department of Munitions turned for help. The firm supplied the design and much of the equipment for an annexe erected by the Colonial Sugar Refining Company at Pyrmont, New South Wales, towards the end of 1941. The C.S.R. Company arranged for the collection of charred coconut shell from the nearer South Sea islands, but when it seemed that the Japanese might cut off these supplies arrangements were made to fall back on other sources. The Chemical Defence Section conducted tests on Australian coals as a possible alternative raw material. Samples of black coal from mines in New South Wales and Queensland, and of brown coal from Victoria, were briquetted, carbonised and then activated with steam in the customary manner. A product moderately satisfactory for use in the container of the general service respirator was obtained by using a mixture of coking and non-coking coals, but it was less effective than that obtained from coconut shell. Activation of charcoal from peach stones was also tried, with no better success: the product was too soft and crumbly. Events proved that the 6,400 tons of imported charred coconut shell, including over 1,000 tons from Fiji, were more than sufficient to meet Service requirements. From this shell came about 600 tons of activated material, on which the Commonwealth Government paid a substantial royalty.

From time to time changes in the manufacture of activated charcoal were introduced. For example, the degree of activation was modified in order to produce a charcoal of greater adsorptive capacity, thus permitting a reduction in the size of the container of the light type of respirator. Another change introduced was the impregnation of activated charcoals with chemicals for counteracting particular gases. During 1940 it was feared that Germany might attack with arsine, a most insidious and almost odourless gas. Increased protection against arsine could be obtained

by impregnating charcoal with silver nitrate.[4] On learning of the British fears, the Chemical Defence Laboratory, in collaboration with the Chemistry Department of the University of Melbourne, worked out methods for the controlled production of the large quantities of arsine needed for testing the respirators specially designed to counteract it.

Another emergency against which the laboratory prepared was the possible use by the Japanese of hydrogen cyanide. Several small, carefully packed, glass containers filled with liquid hydrogen cyanide under pressure were found in a box washed up on the beach at Kota Bharu where a Japanese landing had been attempted.[5] Evidently these grenades had been designed for use against dugouts and tanks. On receiving this report the laboratory at once began experiments on activated charcoal impregnated with pyridine and copper or other metallic compounds to render it more effective against hydrogen cyanide. However as there was no evidence that the Japanese intended to make use of these grenades no action was taken to modify service respirators at that time.

Once the production of the general service respirator had been established and an output of nearly 1,000,000 had been reached (distributed between the armed services and the Department of Home Security), attention was turned to the Light Type Respirator, which had been designed at Porton for issue to commandos, paratroops and tank crews. On account of its light weight the Services demanded it as a general service respirator. Australian army authorities modified the specification for this respirator by requiring that, for the purpose of camouflage, the rubber face pieces be multicoloured instead of black. In view of the known irritant effects of some of the compounding ingredients of coloured rubbers—effects likely to be intensified under tropical conditions—there were considerable misgivings about using them next to the skin. Three rubber companies,[6] working in close collaboration with the Chemical Defence Section, were able to solve the problem by making a laminated rubber mask, the outside layer only of which was coloured.

Manufacture of the container for the light respirator presented a number of new problems. In addition to a more highly activated, finer-grained charcoal which helped to reduce the weight, it required a new lighter type of filter consisting of a mixture of wool and resins which could remove particles efficiently without offering too high a resistance to the flow of air. The first of the new respirators reached the army in August 1943 and before production ceased in the following December approximately 70,000 had been delivered. As far as can be ascertained, these light respirators were not carried in action in the South-West Pacific Area.

A great deal of laboratory work was done at Maribyrnong on testing the efficacy of respirators in removing airborne particles. The ability of

[4] In the charcoal silver nitrate was reduced to silver, which destroyed the arsine by catalysing its aerial oxidation.

[5] Frangible hydrogen cyanide grenades of Japanese origin were examined at the Munitions Supply Laboratories.

[6] Olympic Tyre & Rubber Co Ltd, Ansell Distributors (NSW) Pty Ltd, and Kenny Charlesworth Rubber Pty Ltd.

particles to penetrate the filter of a respirator depended, in a complicated way, on a number of factors; it varied with their size and was at a maximum for particles about .5 micron (.0005 millimetre) in diameter. In other words, particles smaller or larger than this were more readily caught on the filter. In order to make the conditions under which respirators were tested as exacting as possible, it was essential to keep the particle size of all testing clouds close to the maximum penetrative power.

From its experience in testing respirators against airborne particles, the Chemical Defence Laboratory developed a special dust respirator which the army issued to transport drivers in dusty areas. It was found so effective that it became widely used (some 25,000 were made) both by the army and the air force.

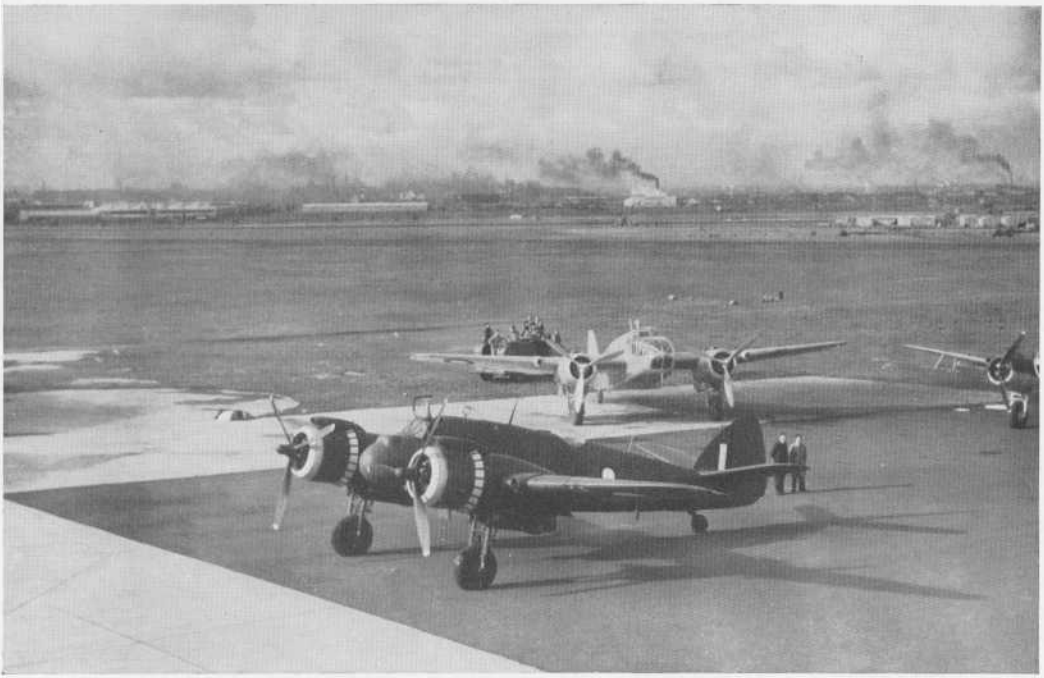
While all this work was being carried out in laboratories and factories, the Services made their preparations. For the purpose of ensuring proper coordination between the activities of the Services and those of the munitions authorities, the scope of the functions of the Chemical Defence Board had been enlarged just before the outbreak of war. As an inter-service body directly responsible to the Defence Committee, its functions included the procurement of materials and equipment from overseas and the investigation of all technical problems in chemical warfare raised by the Services. The composition of the board, which operated under the chairmanship of the Controller-General of Munitions Supply (Mr N. K. S. Brodribb), varied somewhat during the war. In general terms it included technical and operational representatives of the navy, the army and the air force, their respective Directors of Medical Services, and a Munitions Supply Laboratory officer who was the executive secretary (Mr Weldon).

For the first two years of the war—roughly until the threat of invasion by the Japanese—the Services limited their chemical warfare activities to such purely defensive measures as training their members in anti-gas procedures, equipping them with respirators, and maintaining, through the agency of the Chemical Defence Board, a watching brief on related medical and technical problems. However as early as November 1940 Wing Commander Boucher[7] was instructed to investigate the kinds and numbers of chemical air warfare weapons likely to be needed by the R.A.A.F., and to determine whether the main war gases likely to be used by the air force—phosgene and mustard gas—could be manufactured in Australia.[8] Investigations along similar lines were put in hand by the army. The extent to which the emphasis had shifted from defensive to offensive chemical warfare by early 1942 is evident from the following cable sent to Britain by the Defence Committee:

In the light of the present situation in the Pacific, we have considered the desirability of having at our disposal supplies of offensive gas, of which we hold none at

[7] Gp Capt G. W. Boucher. Staff Offr, Tech Services RAAF, 1941-42; Comd RAAF Air Gunners' School 1942-45. B. Toowoomba, Qld, 5 Nov 1903.

[8] No attempt was made to manufacture any chemical warfare agent (except phosgene) on a large scale in Australia during 1939-45. Phosgene was manufactured as a raw material for carbamite at Deer Park, Vic, and some consideration was given to using any surplus production from the explosives industry for chemical warfare if it should prove necessary.

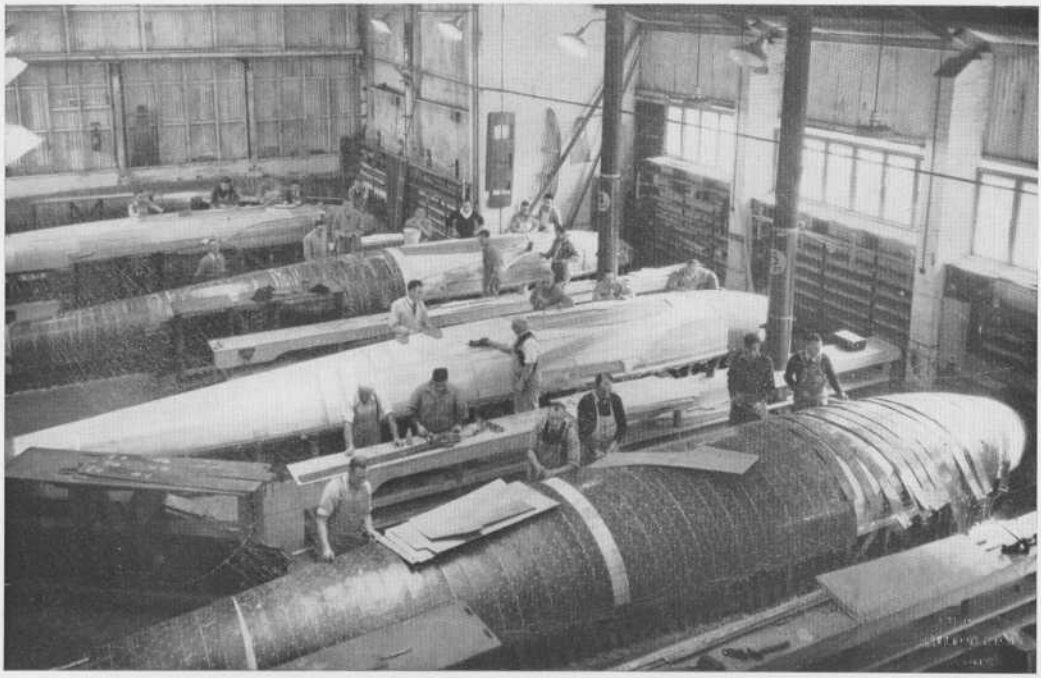


(*Government Aircraft Factories*)

Beaufighter in foreground; Beaufort in background.

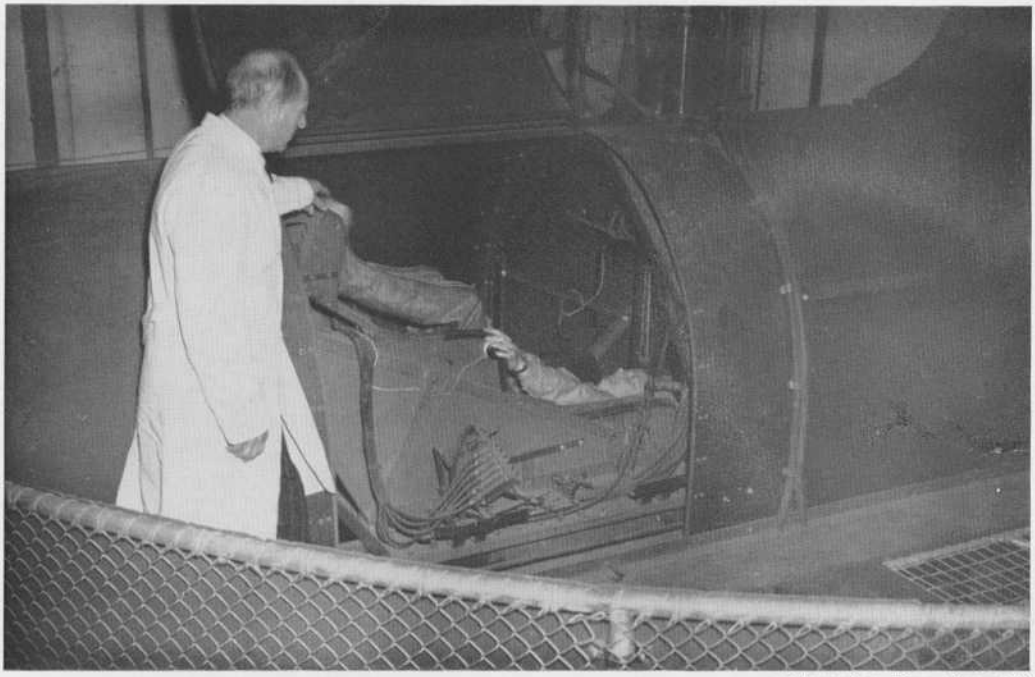


Mustang. (*C.A.C.*)



(De Havilland's)

Gluing-up section of a De Havilland Mosquito fuselage. The curved bands over the shell in the foreground are steel straps used to press the fuselage plywood hard against the mould (part of which can be seen beneath the straps at the right).



(Australian War Memorial)

Testing the Cotton anti-G suit in the centrifuge designed for the purpose. Professor Cotton on the left.

present. We are advised that it would take from 18 months to 2 years to develop capacity in Australia for the manufacture and filling of mustard gas, and before proceeding with such a long-term project it is desired to ascertain if mustard gas in containers suitable for army and air force use could be supplied from the United Kingdom or North America, and if so, the quantities available and probable rates of delivery.[9]

The British authorities advised the Prime Minister of Australia that supplies of chemical air weapons to meet the immediate operational requirements of the R.A.A.F. would be despatched at once. The consignment, comprising light-case bombs of which some were charged with phosgene and others with mustard gas, equipment for spraying mustard gas from aircraft, and bulk supplies of both gases, was of a size intended to give security against gas warfare being launched by the enemy.

The transport over long distances of bulk mustard gas in 3½-gallon cans and 40, 60 and 90-gallon drums, was not without danger. Despite every precaution mustard gas deteriorated with age. The products of decomposition either developed dangerous pressures within the containers or found their way out through leaks, carrying with them undecomposed mustard gas. Constant supervision, periodic "bleeding", and resealing of drums, were therefore necessary. These difficulties were accentuated by the high temperatures and great changes in temperature experienced during the sea voyage through the tropics, and in the subsequent transportation of the gases to stores situated in disused single-track railway tunnels in various parts of the Commonwealth. Some casualties occurred with these dangerous materials, particularly when bulk mustard gas was unloaded in Sydney during the summer, and when phosgene bombs were handled. Thin-walled bombs filled with phosgene were unable to withstand the increased pressures produced by Australian summer temperatures. After being removed from the refrigerated holds of ships, such bombs often leaked and even burst right open. In spite of rigorous precautions, men handling phosgene bombs over long periods suffered cumulative toxic effects, and it became obvious that such bombs could never be used on operations. In their stead the R.A.A.F. ordered a larger, tropically-proven, American bomb.

The arrival of these materials in Australia obliged the Services to appoint scientific and technical officers to deal with the problems attending their operational use. Hitherto scientific experts in chemical warfare in Australia were for the most part to be found in the Chemical Defence Laboratory. However, early in 1942 Wing Commander Le Fevre,[1] Chemical Adviser to the Officer Commanding Far Eastern Command, R.A.F., arrived in Australia from Singapore, where a few days earlier he had supervised the destruction of R.A.F. stocks of chemical weapons before the surrender. Within a short time Le Fevre was appointed to take charge of the organisation of a chemical warfare section within the R.A.A.F.

[9] In mid 1942 General MacArthur issued a directive that full preparation should be made for both defensive and offensive chemical warfare.

[1] W Cdr R. J. W. Le Fevre, DSc, PhD. Reader in Organic Chemistry Univ College, London, 1927-39; scientific adviser to various air force commands 1939-44; Prof of Chemistry, Univ of Sydney, since 1946. B. London, 1 Apr 1905.

The army had already enlisted the help of two chemists: Major Shiels[2] had been appointed full-time chemical adviser to the Engineer-in-Chief at Army Headquarters in Melbourne, and early in 1941 Lieutenant Carter[3] had been posted as chemist (chemical warfare) to Headquarters I Australian Corps in the Middle East, the first occasion this type of appointment had been made in an Australian Service. On his return to Australia early in 1942 Carter was put in charge of the army's newly-formed Chemical Warfare Service.

Before the Services could carry through preparations for chemical warfare on any scale, a large body of technical officers (physiologists, chemists, meteorologists and physicists) had to be formed for the purposes of advising, giving instruction, testing and examining equipment (especially any that might be captured from the enemy) and for carrying out trials on defensive and offensive chemical warfare operations.

The first to be organised were the physiologists. The medical branches of the Services had followed closely the current findings concerning the treatment of gas casualties and medical aspects of defence against gas warfare. In April 1942 the Chemical Defence Board, with the help of a group of Service medical officers, formed the Physiological Sub-Committee, which began its work under the chairmanship of Captain Maxwell.[4] The committee was greatly helped by the University of Melbourne, which placed at its disposal the facilities of the Department of Physiology. Typical of investigations undertaken in the early stages were Dr Trethewie's[5] study of the breathing resistance of respirators, and Dr Corkill's[6] investigation of the possibility of dermatitis being caused by the use of reclaimed rubber in respirators.

Realising that, as a general rule, neither civilian nor Service medical officers possessed any close acquaintance with up-to-date methods of treating gas casualties, the Physiological Sub-Committee arranged for special courses of training and for the reprinting of the *Medical Manual of Chemical Warfare*. After it had been adapted for Australian conditions, some 8,000 copies were printed and distributed with the assistance of the Australian branch of the British Medical Association.

The arrival of Major (later Lieut-Colonel) F. S. Gorrill from Britain in mid-1942 greatly strengthened the medical side of chemical defence. A physiologist of the Royal Army Medical Corps, Gorrill came to Australia at the request of the Department of the Army for the purpose of instructing medical officers, mainly of the Australian Army Medical Corps,

[2] Maj D. O. Shiels, DSc, PhD, MB, BS. (Served 1st AIF.) Medical Officer for Industrial Hygiene, Vic State Dept of Health, since 1937; Chemical Adviser AHQ 1941-42. B. Hawthorn, Vic, 6 Apr 1891.

[3] Lt-Col N. L. Carter. Industrial chemist, Colonial Sugar Refining Co, to 1940; Chemist (CW), I Aust Corps, 1941-42; GSO 3 (CW) First Aust Army 1942; GSO 1 (CW) LHQ 1942-45. Of Perth, WA; b. Perth, 24 Oct 1916.

[4] Maj L. A. I. Maxwell, MD, MSc. Hon Physician, Royal Melbourne Hospital, 1927-50; Consultant C.W. "A" Branch, AHQ, 1940. B. 22 Aug 1890.

[5] E. R. Trethewie, DSc, MD. Tutor in Anatomy then Physiology then Medicine, Queen's College, Univ of Melbourne, 1938-44; Hon Physiologist to Dept of Munitions 1942-44; Prof Experimental Medicine, Univ of Adelaide, 1944-50. B. Launceston, 15 Apr 1913.

[6] A. B. Corkill, MB, BS, DSc. Director, Baker Medical Research Institute, Alfred Hospital, Melbourne, 1938-49. B. North Melbourne, 28 Oct 1898.

in methods of treating gas casualties. Soon after his arrival he began a six-months training course in the Department of Physiology at the University of Melbourne for Service medical officers and practitioners interested in civil defence.

Before 1939 practically all experimental work on gas warfare in the British Commonwealth had been done at the Chemical Defence Experimental Station at Porton, near Salisbury, England. Consequently very little was known about the effects of war gases on the human body under tropical conditions. As soon as the training course had been completed, Gorrill and his group of physiologists moved up to Townsville to explore this little-known field. They made the startling discovery that under the tropical conditions of Townsville, mustard gas was at least four times as effective as it was in the temperate English climate. Sensitive areas of the human body exposed for one minute to a concentration of mustard-gas vapour below 100 milligrams per cubic metre were seriously burnt. Such extreme sensitivity was associated with temperatures greater than 90 degrees Fahrenheit and relative humidities greater than 80 per cent. Under these conditions comparatively small doses of mustard gas produced an unusually sudden onset of disability; skin burns developed more rapidly, with the result that men became casualties in a shorter time. Therapeutic agents for mustard gas were found to be comparatively ineffective unless applied instantly. The British anti-gas ointment fell into this category, as also did the Japanese anti-gas powder, which was particularly ineffective. It was found that the large amount of data which had been accumulated in temperate zones would have to be checked and completely revised if vesicant gases were to be used in the tropics, and that much more research would be needed before chemical warfare could be undertaken in the tropics with any confidence.

Since these important findings, communicated to the Defence Committee in March 1943, were likely to have a profound influence on the tactical employment of toxic gases, steps were immediately taken to retain Gorrill's services for further investigations in Australia. He returned to Britain during 1943 to discuss with the authorities at Porton how best to follow up the results of the discoveries made at Townsville. The Chemical Defence Board was most anxious to cooperate in the further prosecution of this work, and was ready to provide all the scientific resources it could muster.

A proposal made by Major Shiels in April 1942 that a chemical warfare experimental research station should be set up in Queensland, had received the support of the Chemical Defence Board. While it was still being deliberated by the Defence Committee a British Chemical Warfare Liaison Mission made a tour of inspection in Australia. From its observations the mission reached the conclusion that to establish such a station then would be premature. The facilities available at Maribyrnong would, it believed, be adequate for all the experimental work likely to be required in Australia, and in any event there was little possibility that substantial results could be obtained in less than a year. Much of the work proposed

was already being carried out in India, Canada and the Middle East. The mission's report did, however, produce one important, positive result, namely the setting up under the aegis of the Chemical Defence Board of an Experimental and Research Committee, with Mr Weldon as Chairman and Mr E. W. Lanfear, on loan from the British Ministry of Supply, as Secretary. The function of this committee was to direct and coordinate chemical warfare trials and research in Australia. By the creation of three new sub-committees—Physical and Meteorological, Chemical, and Gas Protection—it was able to enlist the efforts of a large body of civilian scientists.[7]

The Chemical Defence Board did not abandon the idea of setting up a research station. After Gorrill returned from Britain in 1943 with a number of scientists from the Porton Research Station, the board formed an experimental unit at Innisfail, North Queensland, where the surrounding rain forest provided conditions closely resembling the tropical jungles of New Guinea and the islands of the South-West Pacific. Here a small team, now consisting of chemists, physiologists, physicists and meteorologists, and technicians, carried out large numbers of tests on a wide variety of both defensive and offensive equipment.[8]

The disadvantages and discomforts of wearing impervious oil-proofed clothing, and the consequent reduction of the efficiency of men wearing it, had become apparent during the war of 1914-18, when it was first employed as a protection against mustard gas. Investigations were therefore made of the possibility of impregnating ordinary fabrics with chemicals which would react with vesicants before they could reach the body. Experimental work carried out along these lines during the period between the wars led to several effective processes being evolved. In one, developed in Britain, clothing was impregnated with a chemical known by the code name of "Anti-verm",[9] which was capable of neutralising the effects of mustard gas. The use of impervious clothing was quite out of the question in the tropics, and so it was to the "Anti-verm" treatment that the Chemical Defence Laboratory turned its attention early in 1942. A pilot plant for operating the process was built and small batches of clothing made from different kinds of material were impregnated for experimental purposes.

A disconcerting discovery made at Innisfail during the summer of 1943-44 was that clothing impregnated with "Anti-verm" was literally worse than useless under tropical conditions: volunteers wearing the clothing in trials conducted in gas chambers became cyanosed owing to the absorption through the skin of the impregnating chemical intended to

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[7] Membership of these committees, including the earlier Physiological Sub-Committee, was as follows: Physiological Sub-Cttee: Dr Ivan Maxwell, Air Cmdre T. E. V. Hurley, Maj D. O. Shiels, P. R. Weldon, Col C. H. Kellaway, Prof R. Wright, Prof P. MacCallum, Prof F. M. Burnet. Physical and Meteorological Sub-cttee: Prof Kerr Grant, S Ldr L. J. Dwyer, Dr C. E. Eddy, F. Pasquill, E. L. Sayce, P. R. Weldon, A. R. Hogg and Dr R. v.d.R. Woolley. Chemical Sub-cttee: Prof J. C. Earl, Dr W. Davies. The Gas Protection Sub-cttee was constituted too late to achieve much useful work—the defensive phase of chemical warfare was almost over. Its members were all drawn from the Services and the Dept of Munitions.

[8] This was essentially an army unit and was known as the Australian Chemical Warfare Research and Experimental Section.

[9] 2:4 dichloro-phenyl-benzoyl-chloroimide.

counteract mustard gas. The Australian Army therefore abandoned "Anti-verm" in favour of C.C.2, a chemical developed in the United States which had proved safe under tropical conditions yet effective against mustard gas. The United States Services of Supply undertook to impregnate protective clothing for the Australian Services if it became necessary.

Scarcely less disconcerting, though no more surprising, was the discovery that the British and American anti-gas ointments first tried in the tropics failed to give any substantial protection. Even the best ointments subsequently evolved were only partly successful.

While it is probable that an increased effectiveness of mustard gas in the tropics was anticipated by physiologists (though the full extent of its intensified action almost certainly was not) the discovery of the ease with which it was dispersed in the jungle came as a complete surprise. Wind speeds at ground level in the jungle are usually only a small fraction of those immediately above the tree tops, but for a given ground wind speed in the jungle the rate of dispersion of mustard gas vapour was found to be several times greater than it would have been for the same ground wind speed in the open. These two factors combined to intensify the effectiveness of mustard gas in the jungle: for a given concentration it was more toxic, and for a given wind velocity it spread more rapidly. In January 1944 the Commander-in-Chief, General Blamey,[1] was briefed as follows:

(*a*) The effectiveness of chemical warfare in tropical areas is likely to be of a completely different order of severity from that existing in the only theatres in which chemical warfare has been employed in the past.

(*b*) As opposed to the effectiveness of chemical agents in a tropical climate is the conclusion that existing defensive measures are very nearly completely ineffective.

By February 1944 much of the testing program planned for Innisfail had been completed. It culminated in a large-scale trial of operational proportions known as the Brook Island Trial. Over four tons of mustard gas were dropped from Beaufort aircraft on a small tropical rain-forest island off the North Queensland coast. The island had been prepared with gas defences, sampling apparatus to measure gas vapour concentrations, and animals for physiological investigations. Volunteers clad in various kinds of British, American, Japanese, and experimental impregnated and impervious clothing were landed immediately; jungle-trained troops with the minimum of protection carried out manoeuvres for several hours over the contaminated territory. Members of the three Women's Services did a great deal of the routine chemical testing on the spot under the direction of chemists and meteorologists. Accurate measurements of the concentration of toxic vapours in the atmosphere were essential for determining the amount of exposure to which volunteers equipped with protective devices could be safely subjected.[2]

[1] Field Marshal Sir Thomas Blamey, GBE, KCB, CMG, DSO, ED. BGGS I Aust Corps 1918. GOC 6 Aust Div 1939-40, I Aust Corps 1940-41; Dep C-in-C ME 1941; GOC-in-C AMF 1942-46. B. Wagga Wagga, NSW, 24 Jan 1884. Died 27 May 1951.

[2] A measure of the intensity of exposure was obtained by multiplying the concentration of the toxic gas by the time of exposure. This product was known as the C.T. value.

A fundamental conclusion reached as a result of this trial was that, under similar conditions in tropical areas, the degree of disability inflicted on occupying troops by using mustard gas would be very much greater than with a corresponding amount of high explosive. In order to test out modified defence procedures and equipment, and prophylactics designed especially for tropical use, further trials were made with air weapons, and low spray attacks with mustard gas on beaches and tropical island fringes.

Throughout the investigations on chemical warfare, great emphasis was placed on results obtained with volunteers. The first volunteers were Melbourne University students who assisted the work of the Chemical Defence Board's Physiological Sub-Committee. When Gorrill moved to Townsville the physiologists became their own guinea-pigs and because the efficacy of vesicant gases in the tropics was unknown at this time, civilian and service medical officers and scientists of his team sometimes suffered very severe internal and external injuries from toxic gases. For most of the Innisfail trials the volunteers were hardened infantry men thoroughly experienced in the techniques of jungle warfare. The morale of these men was outstanding; many of them suffered severe and painful injuries in the earlier experiments. A requirement of the trials was that injured personnel should continue operational duties under front line conditions so that physiologists could discover fully the effect of vesicant gases on the human constitution.

In November 1944, when greatly increased numbers of volunteers were required, R.A.A.F. servicemen in the North Eastern Area came forward. On that occasion they were chosen from men fully acclimatised to living in the tropics. Volunteers in all gas warfare experiments were later awarded commendation cards in recognition of their loyal and unselfish services.

Early in 1944 the importance of the results of the Australian chemical warfare investigations had been recognised by authorities in Great Britain and the United States, who suggested that further work should be carried out in Australia. Both countries offered to assist by providing technical staff and equipment.

On the strength of this advice the Defence Committee decided to transfer the army's Chemical Warfare Research and Experimental Section from Innisfail and to re-form it as a nucleus about which to create an Australian Field Experimental Station at Proserpine, Queensland. The War Cabinet approved a program of building construction designed to accommodate a technical and administrative staff estimated at 650. At the same time it accepted offers of technical assistance from Britain and the United States. Gorrill was appointed Chief Superintendent, and the scientific services comprising sections devoted to chemistry, meteorology, physiology, defensive munitions and photography were placed in charge of Dr Ennor.[3]

[3] A. H. Ennor, DSc. Biochemist at Baker Medical Research Institute, Melbourne, 1938-42; engaged on research with Services and Munitions Dept 1942-46; Prof of Biochemistry, Aust National Univ, since 1948. B. Melbourne, 10 Oct 1912.

In September 1944 South Africa and Canada asked to have representation on the Australian Station, and by January 1945 few self-contained wartime research establishments could have been more cosmopolitan. Australia provided civilian scientists,[4] army technicians and administrative personnel, an R.A.A.F. flight of four Beaufort bombers, meteorologists, laboratory assistants and other technicians, including women of the W.A.A.A.F. and W.R.A.C. The United Kingdom and United States provided civilian scientists and Service chemical warfare specialists; also much of the specialised scientific equipment. Observers came from South Africa, Canada and New Zealand.

Some scientists hoped that in view of the excellent facilities that had been built up at Proserpine, the station would be retained after the war as one of the important centres in the British Commonwealth for all kinds of tropical testing. Indeed a team of three members of the Chemical Defence Board (Lieut-Colonels Gorrill and Carter and Squadron Leader Trewin[5]) was sent to the United Kingdom to explore just this possibility. While they were en route to England a delegation of the British Chemical Defence Board led by Mr J. Davidson-Pratt visited Australia bringing an offer from the United Kingdom to share the total capital and running costs of the Australian Field Experimental Station on a fifty-fifty basis. The capital cost of the station was approximately £250,000 and running costs for the year 1944-5 amounted to about £330,000. After long discussions on running costs, accessibility of the station, climatic requirements and the availability of staff, it was eventually decided to disband the Australian establishment.

Late in the war a related form of chemical warfare—flame-throwing—came into prominence and was used in action. At the suggestion of the Chemical Defence Board experiments were made at Maribyrnong in 1943 to discover a suitable agent for transforming petrol into a thick, viscous fluid suitable for use in flame-throwers or in the break-up type of aircraft incendiary bomb.[6] Several substances, mainly metal soaps, were tried without any great success and the work was abandoned for a while. Later, when the American Army discovered that the flame-thrower using a thickened or "gelled" petrol was one of the most effective ways of overcoming Japanese bunker defence, interest in the work was revived. At the instigation of the M.G.O. Branch the Lubricants and Bearings Section of the C.S.I.R. took up the problem. The agents developed in Britain for "gelling" petrol had proved difficult to use under front-line conditions in the tropics. It so happened that some time before the army made its

[4] They were drawn from the staffs of the Universities of Sydney, Melbourne and Adelaide, the Walter and Eliza Hall Institute, the Baker Institute (of the Alfred Hospital, Melbourne), Innisfail Hospital Board, Commonwealth Solar Observatory, and the Meteorological Bureau.

[5] S Ldr A. H. Trewin, BSc, BEd. O i/c Chemical Warfare RAAF Directorate of Armament, and RAAF technical representative on Chemical Defence Board and Interservice Experimental and Research Cttee, 1943-46. School teacher; of Nathalia, Vic; b. Nathalia, 27 Apr 1916.

[6] Smoke warfare also came under the control of the Chemical Defence Board. After successful trials at Oro Bay and Buna in New Guinea it seemed for a while that smoke-screening against aircraft attacks might assume some importance. However, with continued Allied successes on land, sea, and especially in the air, the need for smoke-screening disappeared by the end of 1944.

request the Lubricants and Bearings Section had been studying metal soaps as lubricants and was thus in a good position to help the army. In collaboration with the Munitions Supply Laboratories the section developed to full-scale production a granular powder—essentially basic aluminium oleate—which the army found highly successful. "Geletrol", as it was called, had the advantage of being easily mixed in the field. At first it was used in "man-pack" flame-throwers of American make.[7] Later, the Department of Munitions produced a mechanised flame-thrower capable of being mounted on tanks. Flame-throwers were used by Australian troops in New Guinea, Bougainville and Borneo in 1945.

Despite the evidence of the great efficacy of mustard gas in the tropics, Allied military authorities were doubtful of the usefulness of gas warfare in the conditions then prevailing. An appreciation of the position made by Carter in February 1944 stated that "while in certain tactical situations in the S.W.P.A. use of gas in the attack would probably prove to be more effective than any other weapon of war, employment of chemical warfare in the S.W.P.A. would be likely to favour the defence more than the attack by generally slowing up operations".

The fact is that neither side at any time used gas warfare. There is no doubt that the Japanese were prepared for it, as indeed were the Italians in the Middle East, from whom the 6th Australian Division captured large quantities of mustard gas at Bardia in 1941. Reports from the Chemical Defence Section at Maribyrnong stated that very little of the Japanese chemical warfare equipment was novel and that much of it was inferior to that of the Allied Forces. One reason why poison gas was not employed in the war of 1939-45, as it had been in the earlier world war, was perhaps that it was considered more horrifying than the time-honoured missile weapons; another that each combatant was known to be well-equipped to counter it; another that tactically it was difficult to handle, and in some situations might harm the user as much as his opponent. The extent to which incendiary bombs and flame-throwers were used suggests that it was lack of confidence in gas as a weapon rather than humane considerations that prevented its re-appearance in the second world war.

[7] In August 1944 LHQ Gas School was reorganised to include a mobile flame-warfare wing which actively engaged in training selected infantry personnel in each main formation outside Australia to use man-pack flame-throwers.

CHAPTER 18

THE AIRCRAFT INDUSTRY

SOON after the war of 1914-18 a number of small firms, encouraged by the Commonwealth Government, began the construction of wooden, fabric-covered aircraft fitted with imported engines, for use as training machines by the R.A.A.F. Once the demand for training aircraft had been satisfied, the firms had little further scope for activity since there was very little demand for civil aircraft of the type they were making. The inevitable result was that they went out of business.

While on a trip abroad in 1935 Mr Essington Lewis saw in the warlike preparations of Germany and Japan a strong argument for establishing a well-founded aircraft industry in Australia. He believed that because of the peculiar distribution of Australia's population, with large cities along the eastern and southern coasts and hundreds of thousands of square miles to the north and west practically devoid of settlement, aircraft would prove a powerful, and perhaps the main weapon of defence. During his stay in London Lewis was able to gain the support of Sir Harry (later Lord) McGowan of Imperial Chemical Industries, and that of Mr W. S. Robinson[1] of the Zinc Corporation Ltd, but on his return to Australia he found that his ideas were by no means widely accepted. Indeed, had it not been for the strong advocacy of Sir Archdale Parkhill,[2] at that time Minister for Defence in the Lyons Government, and of Mr W. M. Hughes, Lewis's proposals for an aircraft industry might well have been shelved.

In 1936, however, at the suggestion of the Government, three companies with long experience in overcoming problems likely to be met in setting up such an industry banded together and formed a syndicate. They were the Broken Hill Proprietary Company Ltd, Australia's leading industrial organisation; Broken Hill Smelters Pty Ltd, a company that handled almost the entire mining and smelting of non-ferrous metals in Australia; and General Motors-Holden's Ltd, the most powerful member of the automotive industry. The purpose of the syndicate was to discover to what extent it would be practicable to develop a self-sufficient aircraft industry based on Australian raw materials and industrial facilities.

The syndicate formed the opinion that about five years would be required to produce first-line military aircraft, and that before this could be achieved much spade work would have to be done. In the belief that it is better to learn to walk before learning to run, it was decided in the first instance not to attempt to make the most modern, high-performance type of aircraft but to begin with a trainer. In view of criticisms that were later made about the inadequacy of the first Australian-made aircraft as fighter planes, it is important to remember this technical policy.

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[1] W. S. Robinson. Financial Editor, Melbourne *Age*, 1899-1907; Joint Managing Director, Broken Hill Assoc Smelters, 1915-35; Adviser, in London, to Aust Govt in first and second world wars. Of Melbourne and London; b. Hawthorn, Vic, 3 Oct 1876.

[2] Hon Sir Archdale Parkhill, KCMG. MHR 1927-37. PMG 1932-34; Min for Defence 1934-37. B. Paddington, NSW, 27 Aug 1879. Died 3 Oct 1947.

In order to decide the best type of aircraft with which to begin manufacture, the syndicate appointed a mission of three engineering officers of the air force—Messrs Wackett,[3] Harrison[4] and Murphy[5]—and sent them abroad with instructions to visit every country of interest as far as aircraft manufacturing was concerned. They were to study the types of aircraft in production and to be prepared on their return to Australia to recommend an aircraft and an engine suited both to the requirements of the R.A.A.F. and to the stage of industrial development that had been reached in Australia. In the course of their travels the mission visited Italy, France, Germany, Czechoslovakia, Holland, England and the United States.

Among the foremost considerations in the minds of the mission when preparing its report was the desirability of establishing a method of manufacture that would be applicable not to one type of aircraft only, but to a range of types. The design should, moreover, lend itself to making the greatest use of jigs and tools so that in emergency, mass production by semi-skilled labour would be possible. It also took the view that the design should include features likely to become standard practice for some years. Features then regarded as novel but sufficiently important in securing a high performance to be included in the requirements of an aircraft for Australian manufacture were: stressed skin construction; all-metal construction; low-wing monoplane; hydraulically operated, retractable undercarriage landing gear; variable pitch propeller. An air-cooled radial engine was selected as the most suitable type to establish aero-engine production in Australia. The members of the mission were told that, other things being equal, British types of aircraft and aero-engine should be favoured, but that the all-important point was to select types which could be put into production in Australia most easily and rapidly.

Having regard to all these requirements, and to the suitability of the aircraft for the advanced training requirements of the R.A.A.F., the mission unanimously recommended that a licence to manufacture an aircraft known as NA-33 should be secured from North American Aviation Incorporated (California) and that authority to manufacture single-row Wasp engines for installation in the aircraft should be obtained from the Pratt and Whitney Aircraft Division of the United Aircraft Corporation. Choice of this engine was strongly influenced by the fact that many components of the single-row Wasp were common to those used in the twin-row Wasp Pratt and Whitney engine of 1,200 horse power, and that the same techniques and methods of construction were used for both engines. Ability to produce the larger engine would be a great asset if it was decided to build operational aircraft.

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[3] W Cdr Sir Lawrence Wackett, DFC, AFC; BSc. (Served 1st AIF.) RAAF 1919-30; Manager C'wealth Aircraft Corpn. Aircraft engineer (designed the experimental flying boat "Widgeon"). Of Melbourne; b. Townsville, Qld, 2 Jan 1896.

[4] W Cdr H. C. Harrison, OBE. Chief draughtsman in aircraft firm, England, 1916-20. Dir of Tech Services RAAF 1925-27, 1930-35; comd various RDF Stns RAAF 1943-44; Dep Dir Repair and Maintenance RAAF 1944-45. Of Middle Brighton, Vic; b. Norwich, Eng, 22 May 1888.

[5] Air Cmdre A. W. Murphy, DFC, AFC. (Served 1st AIF: 1 Sqn Aust Flying Corps.) Comd 4 Maintenance Gp RAAF, 1942-45. Of Essendon, Vic; b. Kew, Vic, 17 Nov 1891.

The NA-33, a two-seater, single-engine, low-wing, all-metal monoplane had been designed by North American Aviation for simplified, large scale production. Its construction in Australia would provide factory experience in manufacturing techniques likely to form a background for the development of other types of aircraft, ranging from high-speed fighters to bombers. By no means least of the advantages of the NA-33 were the very reasonable terms asked for the licence to manufacture it in Australia. The Air Board accepted all the mission's recommendations. Later the British Air Ministry also adopted the NA-33, under the name of the Harvard trainer.

The original members of the syndicate had now been joined by representatives of I.C.I.A.N.Z. Ltd, the Electrolytic Zinc Company of Australasia Ltd, and the Orient Steam Navigation Company Ltd. Almost immediately after this accession to its membership, the syndicate was registered in Victoria as the Commonwealth Aircraft Corporation Pty Ltd (C.A.C.) in October 1936.[6] This organisation not only pioneered the manufacture of all-metal aircraft in Australia, it also became the leading wartime private manufacturer.

While plans were being prepared for the erection of aircraft and engine factories and an engine test-house at Fishermen's Bend (Victoria), Wackett was sent to Britain and the United States to buy machine-tools and equipment and to arrange the necessary licences. Before the buildings were completed in September 1937, the Commonwealth Government had placed an order for forty NA-33's.

It is an interesting sidelight on the ramifications of the Aluminum Corporation of America that the C.A.C. found it necessary in 1938 to procure from it a licence for making special aluminium alloy castings needed for aircraft parts. A foundry built for this purpose began operations in January 1939 with small and relatively simple castings, but as experience was acquired more and more intricate tasks, such as the cylinder head for the Wasp engine, were undertaken. Casting of magnesium and its alloys, also new to Australia, was begun. By reason of experience gained in foundry work involving light alloys, the C.A.C. became the source of supply of aluminium-magnesium alloy castings not only for its own aircraft and engine projects but for all other members of the wartime aircraft industry. Later, these facilities proved insufficient and an additional foundry was built by the Commonwealth Government at Highett, Victoria, for use by the corporation as a magnesium foundry. This enabled the foundry at Fishermen's Bend to be used exclusively for aluminium and its alloys.

Sheet aluminium for the fabrication of wings and other parts of the Wirraway[7] (as the Australian version of the NA-33 was named) was at first imported. It was not until after war broke out that the works of the Australian Aluminium Company at Granville, New South Wales, were

[6] H. G. Darling became Chairman of Directors. Board members were: Sir Colin Fraser, Sir Lennon Raws, Messrs E. Lewis, M. L. Baillieu, A. Johnson and L. J. Hartnett. Mr Wackett was appointed manager.

[7] Derived from an aboriginal word meaning challenge.

ready to begin the rolling and extrusion of ingot aluminium. In August 1941 this company began to extrude metal sections for the construction of spars, and wire, rod and bar for rivets, bolts, nuts and engine parts. It also made, to exacting specifications, alloys for the forging of engine pistons, crank cases, landing gear and propeller blades.

The company specialised in the production of "alclad" sheet. The resistance of aluminium to corrosion depended very much on its purity: the higher the purity the more resistant it was. To take advantage of this fact without at the same time sacrificing the greater strength accruing from the alloying of aluminium, the practice had grown up of using composite sheets of metal consisting of a high-strength alloy core (duralumin) sandwiched between thin sheets of the pure metal. The Australian Aluminium Company produced large quantities of "alclad alloy sheet", for making the Beaufort, Beaufighter, Wirraway and Boomerang.

The steel industry gave powerful support to the infant aircraft industry, by providing constructional materials such as high-grade alloy steels and by fabricating these materials. A vital step in the manufacture of the Wasp engine and later the twin Wasp engine, for example, was the production of forgings by Australian Forge and Engineering Pty Ltd of Lidcombe, New South Wales; likewise the production of cylinder blank forgings by Stewarts and Lloyds of Newcastle. Equally essential to the industry were the chrome-molybdenum steel tubing made by British Tube Mills of Adelaide and the undercarriages made by James N. Kirby Pty Ltd of Sydney.

The licence under which the Commonwealth Aircraft Corporation was authorised to manufacture the NA-33 aircraft contained clauses providing that alterations could, if desired, be made in the design and also in the name of the aircraft. Its fuselage was constructed of welded nickel-chrome-molybdenum steel tubing in four sections, all bolted together. The wings were of single-spar structure covered with a stressed metal skin. The Pratt and Whitney single-row, nine-cylinder, 600-horse power, air-cooled, radial Wasp engines built by the C.A.C. were fitted to the aircraft to drive the three-bladed, metal Hamilton Standard type controllable-pitch propellers. Some details of this, the first aircraft to be made wholly in Australia, are set out below.

Wing span	43 ft
Wing area	256 sq ft
Wing loading	21.8 lb per sq ft
Normal gross weight	5,575 lb
Maximum gross weight	6,450 lb
Top speed at critical altitude (8,600 ft)	220 mph
Operating speeds (2,100 rpm and 28-in manifold pressure):	
at sea level	177 mph
at 9,000 ft	199 mph
at 13,000 ft	209 mph
Landing speed (at normal weight) flaps down	65 mph
Maximum rate of climb	1,950 ft per min

Although a seemingly early start had been made on aircraft manufacture in Australia, it had not been soon enough to allow the development of front-line fighter aircraft in the early years of the war. However it must not be forgotten that trainers such as the Wirraway played a vital role in enabling Australia to meet her extensive commitments under the Empire Air Training Scheme, which were to supply 16,000 fully trained air crew by March 1943, with a further 10,000 each year. In the war Australia produced about 4½ per cent of the British Commonwealth's training aircraft.

The first Wirraway, which was built from imported fabricated aluminium, came off the production line and was flown on 27th March 1939 —approximately two years and nine months after work had begun.

While the Commonwealth Aircraft Corporation was engaged on the Wirraway, the De Havilland Company at Bankstown, New South Wales, began work on the Tiger Moth, a trainer powered by Gipsy aero-engines which, in the first instance, it had been intended to import. When the time came, this could not be done and the engines had to be built locally. The detailed story of the De Havilland Company's activities will be taken up later in this chapter. Suffice it to say here that C.A.C. and De Havilland's had, by the outbreak of war, acquired machine tools and built up substantial groups of skilled workers who made possible the rapid expansion of the aircraft industry that took place at the height of the war. In its factories the C.A.C. is said to have possessed at this period the finest assembly of machine tools in the Commonwealth.

Early in 1939 a British Air Mission led by Sir S. Hardman Lever came to Australia to investigate the possibility of manufacturing here a front-line bomber aircraft. The mission made its report to the Commonwealth Government on 18th March 1939 and before the month was out its recommendations had been accepted. In general terms these were that Australia should undertake the manufacture of an operational aircraft, while Britain would supply as much technical assistance as possible and share the output and the costs. The aircraft recommended was the Bristol Aeroplane Company's Beaufort bomber.

As a first step in carrying out the agreement the Commonwealth Government set about establishing two main centres, one at Mascot, New South Wales, and the other at Fishermen's Bend, Victoria, for the final assembly of aircraft. For the purpose of administering these centres it created, in July 1939, the Aircraft Construction Branch within the newly-established Department of Supply and Development. The branch was placed under the direction of Mr Harold Clapp, who had resigned from the chairmanship of the Commissioners of the Victorian Railways to take up his new post.[7]

The general position on the outbreak of war was roughly this. The R.A.A.F., consisting of about 3,500 officers and men, possessed about 250 aircraft of which only two-thirds were suited for military operations,

[7] Mr F. J. Shea became Chief Engineer, having been released on loan to the Commonwealth from his work as Chief Mechanical Engineer of the South Australian Railways. Mr V. F. Letcher, formerly Manager of the Publicity and Tourist Services in the Victorian Railways, was appointed Superintendent of Administration.

and many of them were already obsolete. About 12 Wirraways had been built; preparations for producing the Tiger Moth were well in hand but the Beaufort organisation was only just beginning to take shape.

With the intention of coordinating the activities of private and government aircraft factories the Federal Government in March 1940 replaced the Aircraft Construction Branch with the Aircraft Production Commission, a statutory body responsible at first to the Minister for Supply and Development and, after June 1940, to the Minister for Munitions.[8] Later events proved that this arrangement was unsatisfactory and the Government was, as will be seen later, obliged to introduce yet another change in the administration of the wartime aircraft industry.

The Beaufort bomber chosen for manufacture in Australia was a versatile aircraft, adaptable for long-range reconnaissance or for use as an ordinary bomber or a torpedo bomber with a range enabling it to operate over wide expanses of land and sea. It appeared to be ideal for the defence of a large continent such as Australia which could be attacked only by forces operating from fairly distant bases. Moreover, it was of a type that lent itself to production under the industrial conditions then prevailing in Australia.

At the time the British mission made its recommendations the Beaufort prototype had just passed its first trials in England. The Beaufort was an all-metal, mid-wing, twin-engine monoplane. Since the manufacture of an aircraft of this kind had never before been attempted in Australia it is of interest to record some of its technical details:

Engine	Pratt and Whitney, 1,200-hp, twin-row Wasp, 14 cylinders, air-cooled radial.
Propellers	3-bladed, 11 ft 6 in diameter, Curtis Electric or Hamilton Standard, constant-speed, fully feathering.
Span	57 ft 10 in.
Length	44 ft 4½ in.
Wing area (gross)	503 sq ft.
Wing area (net)	451 sq ft.
Over-all height (to tip of radio mast)	14 ft 5 in.
Tare weight	13,000 lb.
Maximum all-up weight	21,500 lb.
Service ceiling	25,000 ft.
Absolute ceiling	26,000 ft.
Maximum rate of climb	1,200 ft per min up to 7,000 ft. 880 „ „ „ „ „ 15,400 ft.
Range	1,600 miles. 1,060 miles.
Speeds (all-up weight 21,000)	
At rated power, at sea level	232 mph
at 8,500 ft	259 mph
at 15,900 ft	267 mph.

[8] The members of the Commission were: Chairman, H. W. Clapp; Executive Members—J. S. Storey (former Director of Manufacturing, General Motors); R. Lawson (Director-General of Production and Supply, Dept of Air); A. V. Smith (Chairman, Contracts Board, Dept of Supply); E. R. Mitchell (a Sydney chartered accountant) representing the Treasury until Oct 1941 when he was succeeded by W. T. Harris; Secretary, V. F. Letcher.

In addition to a total of 1,000 pounds of bombs in the bomb bay, two 500-pound bombs could be carried under the wings. Alternatively a 2,000-pound torpedo (either English Mark XVIII or American Mark XIII), mine or bomb could be slung in the bomb bay with the doors fixed open. If necessary, an auxiliary fuel tank of 138 gallons' capacity could be carried in the bomb bay instead of bombs.

The arrangement under which torpedo bombers were to be manufactured in Australia was that the Bristol Aeroplane Company should supply all engineering and tooling drawings and all the requisite technical data. Originally the intention had been that most of the difficult components of the aircraft, such as engines, propellers, gun turrets, undercarriages, tail-wheel struts, aircraft instruments, aircraft steels, and light alloy parts, should be manufactured in England, and that little more than assembly of the 39,000 different component parts in each aircraft should be attempted in Australia. This was the plan being carried out in the early days of the war, between September 1939 and the middle of 1940, but at the end of July 1940 a cable was received from the United Kingdom Air Ministry which read:

> From this date onwards Australia can rely on England for no further supplies of any aircraft materials or equipment of any kind.

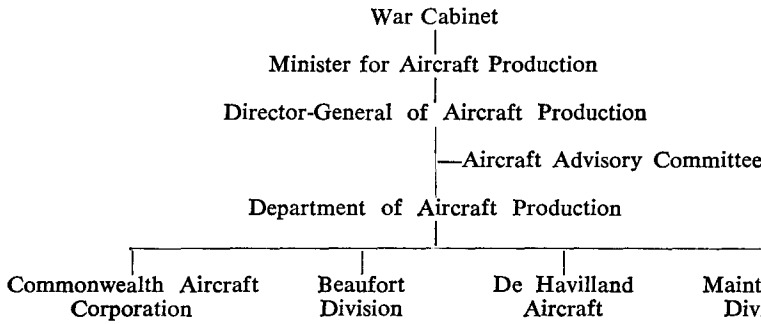
This message caused great consternation among the members of the Aircraft Production Commission, forcing them to make up their minds immediately whether to recommend the Government to proceed with the project or not. It was the death blow to hopes that the first Beauforts would be delivered during 1940 as originally planned. Three months after this embargo had been imposed, it was relaxed sufficiently to permit the Bristol Aeroplane Company to complete its undertaking to supply parts for the first twenty Beauforts; otherwise the whole project might have collapsed.

> Looking back from this point (commented Sir John Storey), I think I can say it was fortunate that we had not the slightest appreciation of the difficulties with which we would be confronted. Had we had any conception of these difficulties I feel we should have recommended the abandonment of the project. As it was, we decided to follow a good old Australian policy and give it a go.

There were to be many periods when failure would threaten the whole venture.

Australia now faced perhaps her biggest and most complex industrial task of the war. An English aeronautical expert at this time expressed the opinion that the building of Beaufort bombers was beyond the capacity of Australia. It meant that, in a short space of time, the country would be compelled to build, from the ground up, a vast organisation for the mass production of an intricate machine that would necessitate the creation not merely of a single industry, but of a large group of related industries. The enlargement of the Government's participation in the industry from merely assembling aircraft from imported components to manufacturing aircraft wholly in Australia called for a radical overhaul of administrative

machinery. In the earlier planning insufficient attention had been given to the problem of achieving coordination between government and private industry. The industry now began to assume such proportions that it could no longer be satisfactorily administered as part of the Department of Munitions. In June 1941 the Government created the Department of Aircraft Production and placed it under the direction of Mr Essington Lewis.[9] To assist him it set up the Aircraft Advisory Committee.[1] The organisation for the production of aircraft took the form shown in the accompanying chart.



Late in 1941 the Beaufort Division, which had been placed in charge of Mr Storey, accepted full responsibility for the manufacture of every part of the aircraft, including gun turrets and excluding only armament. This did not mean that every part of the aircraft was manufactured in the Beaufort factory at Fishermen's Bend; engines, propellers, undercarriages and electrical accessories for engines were all made in annexes in different parts of the Commonwealth. At no time was there any question of making these parts in one big central government factory; this would have involved the country in an enormous capital outlay and left it with a largely unwanted plant after the war. Instead, an organisation was required which would be capable of using the facilities of peacetime industry wherever they could be found. This, with variations according to differing circumstances, was the general pattern adopted in manufacturing all the more complex munitions of war: aircraft, tanks, torpedoes and ships. It was a difficult business to build up such an organisation under wartime conditions. Well-defined principles that had been successfully applied in older industrial countries had to be adapted to a country of small population and limited resources, both widely dispersed.

The basic plan, briefly stated, was to spread the manufacture of component parts by sub-contracting among about 600 firms, some of them in

[9] The Aircraft Production Commission was administered by the Dept of Aircraft Production until Jan 1942, when it went out of existence.

[1] Members of the committee included: Hon D. Cameron (Minister for Aircraft Production); Essington Lewis (Director-General of Aircraft Production), Chairman; D. McVey, V. F. Letcher and W. T. Harris (Dept of Aircraft Production); Air Cmdre E. C. Wackett (RAAF); H. G. Darling (C'wealth Aircraft Corporation); A. Murray Jones (De Havilland Aircraft); J. S. Storey (Beaufort Division); F. J. Shea (Aircraft Maintenance Division); L. P. Coombes (CSIR Division of Aeronautics); E. V. Nixon (Treasury); N. Roberts (Trades Unions); L. J. Wackett, Chief Technical Adviser.

centres more than 1,000 miles apart. Components made by these sub-contractors were fed into seven factories, where they were assembled into the main sub-units of the aircraft. Here the workshops of the State Railways of Victoria, New South Wales and South Australia contributed a major share, distributed among them as follows:

Chullora (N.S.W.): front fuselage, stern frame, undercarriage and engine nacelle.
Newport (Vic): rear fuselage and tail assemblies, tail plane, rudder fins and elevator.
Islington (S.A.): centre plane and wings.

The major sub-assemblies were in turn fed into the main assembly workshops at Fishermen's Bend and Mascot, where the final fitting out was undertaken before the aircraft were moved out as complete units ready for flight testing.

The first Beaufort flown in Australia, early in 1941, was an experimental aircraft assembled from parts supplied from the United Kingdom. The first Australian-built[2] Beaufort made its flight in August 1941, within two years and three months of the decision to manufacture.

Although built to the design of the British aircraft, the Australian Beaufort was not an exact copy. It was found as a general rule that minor changes had to be made to meet the requirements of the R.A.A.F. One of the principal reasons for these changes was the fact that aircraft designed for operation in the conditions prevailing in Britain and in the United States were not necessarily suitable for flying in the hot, often humid, tropical areas of Northern Australia and the islands of the South-West Pacific. Some modifications incorporated improved features that had been developed locally; others permitted the substitution of indigenous raw materials, which were seldom identical with those specified.

The most important modification concerned the engine. The original intention, following the recommendations of the United Kingdom Air Mission, was to use British-made 1,000-horse power Taurus engines in Beauforts until they could be made in Australia. The Taurus engine, however, proved a complete failure in Britain and was never produced in quantity there. For this reason the Aircraft Production Commission decided to substitute American twin-row Wasp engines, which could then be imported and for which facilities for local manufacture were being built up.

In order to accommodate the more powerful twin-row Wasp engine (1,200 as against 1,000 horse power) in the airframe designed for the Taurus engine, it was necessary to redesign many parts of the aircraft. The very considerable work involved was rewarded with an aircraft that flew faster than its British counterpart. Among other innovations were the installation of armour plate to protect the pilot from rearward and frontal attacks, and a gun turret with increased rotation (from 180 to 240 degrees). To correct a tendency of the original Beaufort to yaw, the fin

[2] Except for the engine; the first Australian-built Beaufort engines were not completed until Nov 1941.

was redesigned and its area increased by some 15 per cent. A special "shimmy damping" arrangement designed in Australia by National Motor Springs Ltd, entirely eliminated what was known as tail wheel "shimmy".

The problem of transferring from the United Kingdom to Australia the great mass of technical information embodied in more than 250,000 specifications and accompanying drawings used by aircraft and other manufacturers was a formidable one. To have sent this bulky material by ship would have been much too slow; by air it would have overtaxed the hard-pressed transport facilities. The problem was solved by greatly reducing the volume of the material through the use of microfilm, a procedure first introduced during the Franco-Prussian war.[3] During the siege of Paris several lengthy messages were sent to the outside world by photographing them, greatly reduced in size, on rolls of film sufficiently small to be fastened to the leg of a carrier pigeon. Except for the substitution of aircraft for pigeons essentially the same technique was used in successfully transferring from the United Kingdom and United States much of the technical information needed by Australia in the second world war.

The Beaufort Division could not have achieved what it did without outside help over and above the technical information, drawings and machine tools provided by the Bristol Aeroplane Company. Members of the nucleus technical staff chosen from the State railway engineering workshops and sent for training at the works of the Bristol Company later assumed leading positions in the Beaufort project in Australia and in due course, in the Beaufighter and Lincoln projects. Key men drawn from the company's own experienced engineers included Mr J. A. Latham and Mr J. H. Crovine, who became Chief Engineer and Chief Inspector respectively of the Australian project. Indeed the generous assistance of all kinds received from Britain—from the Air Ministry and the Bristol Aeroplane Company in particular—never ceased. In the darkest days, when she stood alone and was unable to supply all the materials originally intended, Britain continued to give help to Australia even though it meant reducing the slender stocks that were all she had to stave off defeat. "The Australian people can never be grateful enough for the wonderful spirit which was manifested by aircraft authorities and manufacturers in the United Kingdom at that stage and since."[4]

Valuable assistance was also given by the United States, especially through the agency of the Lend-Lease plan; much of this help was due to the generosity of British authorities in sponsoring Australian requests for aircraft materials even when they could only be met at the expense of British orders.[5]

The Beaufort organisation was strengthened by recruiting leading production engineers from Australian industries. Mr E. J. Gibson (Construc-

[3] K. Burrow and D. P. Mellor, "Microfilms for the Scientist and the Scholar", *Australian Journal of Science*, Vol. 9 (1945), p. 4.

[4] Sir John Storey, *Aircraft Production* (Jul 1945), p. 342.

[5] Supply Liaison Offices were maintained in both Britain and the United States; the former, at Australia House, was in charge of Mr A. E. Hyland; the latter, known as the Aircraft Division, was part of the organisation controlled by the Director-General of Aust War Supplies Procurement at Washington.

tion Engineer for General Motors-Holden's) for example, was responsible for the construction of most of the aircraft factories built in Australia during the years 1939-45; Mr Woodfull[6] was Chief Executive in charge of the Supply organisation; and finally Mr M. D. Penn (Factory Manager for De Havilland), originally in charge of the production of Tiger Moths, supervised the production of wings and centre planes for both Beauforts and Beaufighters.

The transition from building aircraft with imported components to manufacturing them almost wholly in Australia was of course made only gradually. As the war progressed considerable extensions had to be made to existing industrial establishments to enable them to manufacture the more specialised aircraft components. In some instances entirely new manufacturing plants had to be set up. These usually took the form of annexes, originally established by the Commonwealth Government as part of the Beaufort scheme but extended, as the needs of the R.A.A.F. and Allied Air Force operating from Australia grew, to meet the requirements of the aircraft industry as a whole.

A major extension was the engine factory erected at Lidcombe, New South Wales, by the Commonwealth Aircraft Corporation on behalf of the Government for producing twin-row Wasp engines for the Beaufort bomber. The C.A.C. had gained experience of engine manufacture by making the single-row Wasp for the Wirraway.

The Lidcombe factory, which was designed to turn out forty engines a month, produced its first in November 1941; the sixty-sixth engine, the first to be constructed entirely from locally-made parts, passed its test on 2nd June 1942. As an insurance against destruction by enemy action of the only source of twin-row Wasps, plans were made to duplicate this factory at Fishermen's Bend, but because it was impossible to obtain the necessary machine tools from the United States this second factory had to restrict its activities to making engine parts for the Lidcombe factory and was never able to make complete engines. Despite a steady flow of twin-row Wasp engines, the output was sufficient to meet only part of the aircraft industry's needs. As many as 37 Beauforts were delivered in one month, each fitted with two engines. Consequently, although nearly 1,000 twin-row Wasps were made at Lidcombe a much larger number had to be imported from the United States. Had Australia been cut completely off from oversea supplies, the restricted facilities available for making aero-engines would have set severe limits to aircraft production. More engines could have been made if the factory had not accepted orders from the United States Army Air Force for spare parts to the value of about £2,000,000, and had not undertaken the repair and overhaul of large numbers of engines for the R.A.A.F. and American Air Force.

Towards the end of the war the factory turned over to making parts for the Rolls Royce Merlin engines, to be assembled with parts obtained

[6] M. B. Woodfull. (Served 1st AIF.) Factory Manager, General Motors-Holden's, 1933-39; Supply Manager and Dep Dir, Beaufort Div, Dept of Aircraft Producn, 1939-45; Gen Manager, Govt Aircraft Factories, Vic, since 1948. Of Melbourne; b. Kerang, Vic, 23 Oct 1895.

from Britain into complete engines. This it ultimately did with success, working under licence from Rolls Royce. The Merlin engine was chosen for manufacture because it was required for the Mosquito, Mustang and Lincoln—types of aircraft most used by the R.A.A.F. at that stage of the war. As the factory could not make all the engines required for Mosquitos and Mustangs, some were imported from the United States under Lend-Lease. American authorities, however, refused to sponsor the importation of Merlin engines for use in long-range bombers such as the Lincoln, on the ground that such aircraft could easily be flown out either from Britain or from the United States. The war ended while the initial order for 100 Merlin engines for the Lincoln bomber was being completed.

The manufacture of retractable landing gear, principally for the Beaufort, was undertaken in an annexe operated on behalf of the Government by National Motor Springs Pty Ltd of Alexandria, New South Wales. This company, without the advantage of any data on manufacturing procedure or designs for tools, succeeded in meeting all the requirements of tail-wheel struts and oleo legs for the Beaufort, and later for the Beaufighter and the Lincoln bomber, at a cost of about half the landed cost of the same components from the United States. All the varied electrical accessory equipment for aero engines—starters, generators, voltage regulators, magnetos and many other units—was made in an extension of the factory of Tecnico Ltd at Marrickville, New South Wales.

Aircraft instruments were not made in Australia before the war, and one of the important tasks of the new industry was to provide ample supplies of these instruments. Their manufacture was spread over three firms. At the works of Amalgamated Wireless (Australasia) Ltd a whole factory was devoted to making compasses, the Sperry gyro horizon, Sperry directional gyro, rate-of-climb indicator, pressure gauges and altimeters. Warburton Franki Ltd of Melbourne concentrated on such equipment as ammeters, voltmeters and air temperature indicators, while H. A. Chivers of Melbourne made tachometer generators, tachometer indicators and turn-and-bank indicators.

In selecting the directional gyro for special mention two considerations have been uppermost: it was then the only device affording fixed directional reference in the cockpit of an aircraft in flight; and its manufacture called for considerable skill. The instrument was introduced into the manufacturing program at A.W.A. in January 1942. The greatest care had to be exercised in keeping the premises where it was made free from dust. Traditional watch-making anti-dust practices were not good enough; even the type of clothing worn by the employees concerned was carefully regulated. The gyroscopic movement of the instrument had a speed of 11,500 revolutions per minute (an ordinary electric fan made 2,000 at the most), and being delicately poised could be irreparably damaged if small specks of dust were allowed to enter the pivots or ball races. Operatives were trained to establish by a sense of touch the permissible "play" of 0.0005 of an inch in dynamically balancing the unit. The permissible

machining tolerance in making the parts of the gyroscope was one ten-thousandth of an inch. Difficulties caused by the unusual features of its castings held up production for several months, but by September 1942 the target of 30 instruments a week was reached. A.W.A's contract ended in May 1945, by which time more than 2,000 instruments had been made.

Coupled with the directional gyro was the gyro-horizon, a device which created for pilots an artificial horizon so that the orientation of an aircraft with respect to the earth's horizon could be indicated accurately without the earth's horizon being visible. Like the directional gyro it consisted of a spinning wheel (15,000 revolutions a minute) supported by gimbals, but it was also fitted with a pendulum and vanes which automatically corrected any drift error caused by friction in the bearings. More than 2,000 of these instruments were made.

A survey of the facilities for the overhaul and maintenance of instruments disclosed that Australian National Airways Ltd was the only company in the Commonwealth with the equipment and trained staff needed to maintain the Sperry gyroscope instruments. It was therefore invited to operate an instrument maintenance annexe established by the Government for this purpose.

The manufacture of constant-speed propellers for Beaufort, Wirraway and other aircraft was entrusted to De Havilland Aircraft Pty Ltd. To keep pace with the enlarged aircraft program of 1942 an additional propeller factory was built to make full-feathering types of propeller, and this too was operated by De Havilland's. Before the war ended many hundreds of propellers were made, and hundreds more were overhauled and repaired.

Forgings for propeller blades and hubs and for engine crank cases and other heavy types of forging in light alloy materials, were produced in an annexe erected near the works of the Australian Aluminium Company Pty Ltd. Here a 35,000-pound drop hammer, the largest of its kind in Australia, was constantly in operation. This hammer, which was built in the United States, had originally been intended for France and was lying on the docks in New York ready for shipment just as the fall of France was announced; it was promptly diverted to Australia.

Metal propellers were checked for possible failure by means of an electric strain gauge, which when used in conjunction with electronic and film recording devices, permitted the measurement of stresses occurring during flight or ground running. Equipment used for this work was imported from the United States and was widely used to ensure safety in Australian propeller installations.

In anticipation of a world shortage of aluminium De Havilland's undertook the design and manufacture of propeller blades from laminated, compressed, impregnated Australian timbers.[7] Development work carried out along these lines in conjunction with the Division of Forest Products

[7] Normal seasoned wood had a sponge-like, porous structure into which the small molecules of phenol and formaldehyde readily penetrated. When wood impregnated in this manner was heated, the two chemicals reacted to form a resin (bakelite). If it was then subjected to great pressure, any air that remained was driven out, and the volume might shrink by as much as two thirds. Wood modified in this way, known as compreg, was both dense and strong.

proved that, had the need arisen, Australia could have become independent of imported aluminium for propeller blades. The wooden blades were first fully tested on the Wirraway.

Owing to the difficulty experienced in obtaining aircraft gun-turrets and armament from overseas, a gun-turret annexe under the control of the Beaufort Division was built at Fairfield, Victoria, for the manufacture of these parts. Here other items required for the Beaufort Division—gun mountings, gear for the release of bombs, equipment for remotely controlling the depth setting of torpedoes, etc—were designed, developed and manufactured.

Early in the development of Australia's wartime aircraft industry it was found that the spacious, well-equipped factories and the organising and engineering experience of the staff of General Motors-Holden's Ltd could be used for the production of important aircraft components. At its Woodville, South Australia, factory, the largest motor-body manufacturing plant in the British Commonwealth, techniques that had been used for producing pressed metal parts for motor vehicle bodies were applied to making the 13,600 separate pressed metal items needed for each Beaufort bomber. Altogether some 9,590,000 parts were made at Woodville and supplied as 1,694,000 sub-assemblies and 25,670 main assemblies for the Beaufort. Similar numbers of parts were supplied for the Beaufighter. Thousands of fuel and oil tanks for all kinds of aircraft were made by General Motors. At its Pagewood, New South Wales, works the company made Gipsy Major engines for Tiger Moths, and fuselages and wings for Mosquito aircraft.

Richards Industries Ltd at Mile End, South Australia, did similar work in the field of metal pressed parts. Supplementing its work for the Beaufort Division on Beaufort, Beaufighter and Lincoln aircraft, this company made wings for Wirraways as well as major and minor components for several other types of aircraft.

Without its automotive industry Australia would not have been able to build aircraft on the scale attained at the height of the war. The industry's experience in sub-contracting made it an ideal coordinating contractor, accustomed as it was to bringing parts and sub-assemblies from hundreds of different factories and assembling, testing and delivering to a pre-arranged time-table. The automotive industry was able to inject into aircraft production the experience and training of its executives, production supervisors and foremen. In highly technical matters, aircraft engineers were essential, but for running the factories executives drawn from the automotive industry were the key men. In the opinion of some authorities, one reason why the manufacture of aircraft was more successful than that of tanks in Australia was that the direction of the former industry made greater use of men experienced in production engineering.

While there was no lack of equipment for fabricating light alloys, the same cannot be said about the principal component of the alloys, namely

ingot aluminium. Early in 1941 it was the cause of much anxiety: the 1940 quota from the United States had not arrived and prospects of supplies for the next two years grew more and more uncertain. Serious consideration was given to setting up a plant for extracting aluminium in Australia. Efforts to obtain the necessary technical information from America failed. Even if they had been successful it was unlikely that aluminium could have been produced in less than three years from the time construction of a plant was begun. The attempt was therefore postponed. It was not until the threat of Japanese domination of the Pacific had been removed that the authorities responsible for supply breathed more easily. Had supplies of aluminium failed, the aircraft industry could not have carried on. Fortunately for Australia the Canadian Aluminium Company not only managed to supply some 20,000 tons of the ingot metal over the war years, but also supplemented this with a good deal of fabricated metal.

In terms of the numbers of people employed, maintenance, repair and supply of spare parts for aircraft formed a major part of the aircraft industry; at one period of the war more people were employed on maintenance and repair work than on production. Maintenance and repair of aircraft were carried out in the workshops and depots of the R.A.A.F. and the civil airline organisations. For the first two years of the war the R.A.A.F. assumed responsibility for the upkeep of aircraft belonging to the Home Defence Forces; the civil airline operators, working under the control of the Aircraft Production Commission, were responsible for aircraft used in the Empire Air Training Scheme. When Japan entered the war and large numbers of American operational aircraft began to arrive in Australia the existing facilities became quite inadequate and the Government immediately took steps to improve them.

Instead of increasing the repair and overhaul facilities of the R.A.A.F. establishments, the Government decided to improve the facilities of commercial airfields near the mainland capital cities, in the hope that once these additions had served their wartime purpose they would be used for greatly expanded commercial air services after the war. This policy was modified for a brief period, during the critical months of threatened invasion, when plans were made to set up repair and maintenance depots in inland centres, but once the danger of invasion had passed the modified plans were dropped and the original program resumed.[8] In the next two years, and at a cost of approximately £3,000,000, the Government built overhaul workshops, machine shops and hangars covering an area almost ten times that devoted to this kind of work before the war; the number of persons engaged on maintenance and repair work reached a maximum

[8] The principal civilian aircraft and engine overhaul contractors were: Australian National Airways Ltd (all mainland States); Qantas Empire Airways Ltd (Qld, NSW and WA); General Motors-Holden's Ltd (Qld and WA); Ford Manufacturing Co of Aust Ltd (Qld); Aircrafts Pty Ltd (Qld); Ansett Airways Ltd (NSW and Victoria); Butler Air Transport Pty Ltd (NSW); De Havilland Aircraft Pty Ltd (NSW); Clyde Engineering Co. Ltd (NSW); Newcastle Aero Club (NSW); Commonwealth Aircraft Corporation Pty Ltd (NSW and Vic); Victorian and Interstate Airways Ltd (Vic); Guinea Airways Ltd (SA); MacRobertson Miller Airlines Ltd (WA).

of 12,000 by May 1944. The scope of their activities then covered a growing proportion of R.A.A.F. operational aircraft as well as the United States Army Air Force and to a lesser extent the Netherlands East Indies Forces, the Royal Navy, the Royal Air Force and the Royal New Zealand Air Force. From early 1942 to the end of 1944 Australia was the chief maintenance and supply centre for the United States Army Air Force in the South-West Pacific Area.

Repair and overhaul contractors were also called upon to assemble and carry out modifications to new aircraft, strengthening important components, fitting long-range fuel tanks, installing gun turrets and fitting additional armament. When the war ended the civilian organisations had repaired and overhauled 11,770 engines and 4,155 airframes. Of these, 5,000 engines and 1,500 airframes were overhauled for the United States Army Air Force in the largest individual servicing undertaking set up: an establishment formed by converting the Rocklea Small Arms Ammunition Factory for use by General Motors-Holden's Ltd and the Ford Manufacturing Company of Australia Ltd.

The Maintenance Division of the Department of Aircraft Production played a most useful part in fostering the manufacture of aircraft spare parts in privately-owned workshops. Notable developments were the manufacture of sodium-filled engine valves, copper-lead and silver-lead bearings, light-alloy pistons and aircraft piston rings. Up to August 1945 the total value of spare parts supplied through this division to the R.A.A.F. and U.S.A.A.F. exceeded £30,000,000, the cost of equipment supplied to the latter being charged to Reverse Lend-Lease.

Although the first aircraft manufactured in Australia were entirely of British and American design, the industry was soon beset with many technical problems. The need for research and testing laboratories without which the building of aero-engines and the design and development of new types of aircraft would have been impossible, had been clearly foreseen by the Secondary Industries Testing and Research Committee in 1937.[9] The committee did no more than make tentative recommendations[1] since it was aware of an impending visit by Mr Wimperis,[2] Director of Scientific Research in the British Air Ministry and an outstanding scientist and administrator, whose services had been made available to the Commonwealth Government.

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[9] In this account of the activities of the CSIR Division of Aeronautics, use has been made of two articles by Mr L. P. Coombes, Chief of the Division: "Aeronautical Research in Australia", *Aircraft*, Vol. 24 (Jan 1946), p. 15, and "Ten Years of Aeronautical Research", *Aircraft Engineering*, Vol. 21 (1949), p. 140.

The earliest aeronautical research carried out in Aust was the work of one man, Lawrence Hargrave, records of whose work are to be found in the *Journal of the Royal Society of NSW*. Owing to the disorganised state of the scientific publications on the subject at that time, and owing to the fact that he worked in great isolation from others with the same interest, much of Hargraves' researches consisted of rediscovery. There is no doubt that he was the originator of the box kite and that his writings were studied by the Wright Brothers during the early stages of their work. Santos-Dumont and Voisin were among the pioneers influenced by Hargraves' researches and publications, the last of which ("Rigid Stable Aeroplanes") was read before the Royal Society of NSW in 1909.

[1] *Report of the Secondary Industries Testing and Research Committee*, Appendix IV (1937).

[2] H. E. Wimperis, CB, CBE; MA. Inventor of aircraft instruments; Director of Scientific Research, Air Ministry, 1925-37. B. 27 Aug 1876.

In a report to the Commonwealth Government in December 1937 explaining why an aeronautical research laboratory was necessary and what might be expected of it, Wimperis wrote:

> It is natural that it should be asked whether Australia by reliance on research work done elsewhere, could not obtain all the information it will need. The answer is that it could not. . . . Australia will wish to know the degree to which home-produced products can safely be used in substitution for materials which have to be imported, how far it is safe to adopt novel methods of manufacture which may suit local conditions, and, most important, to learn promptly the cause of any failure during manufacture or use, of any aircraft component, or of the aircraft as a whole.
>
> Moreover, if for local reasons any modifications are desired in a given design of aircraft, a study must be made in advance of the effects of such modifications. Sometimes the results can be predicted by calculation and sometimes they can not; in the former case an experimental confirmation is usually found desirable, whilst in the latter, experiment is the only means available of arriving at the answer. Such experimental investigations cannot well be carried out many thousand miles away—despite the readiness, which it is safe to assume, at Teddington or Farnborough to undertake them. They must be made in Australia and be available at once.

Wimperis made three specific recommendations:

(*a*) that an aeronautical research laboratory (costing about £140,000), whose main features he outlined, should be established;

(*b*) that a chair of aeronautics should be created in one of the Australian universities; and

(*c*) that an aeronautical research committee should be formed.

In accepting these recommendations the Government decided that (1) the aeronautical research laboratory should become the responsibility of the C.S.I.R.; (2) the University of Sydney should be asked whether, if financial assistance were provided, it would establish a chair in aeronautical engineering; and (3) the setting up of a research committee should be deferred until the first two recommendations had been fully implemented.

Accordingly construction of the Aeronautical and Engine Testing Research Laboratory at Fishermen's Bend, in close proximity to the Commonwealth Aircraft Corporation's plant and to the site of the proposed government aircraft factory, was begun in August 1939 and though the laboratory as a whole was not completed until about the end of 1941 part of the building was ready for occupancy by April 1940. On its completion the Research Laboratory became the headquarters of the Division of Aeronautics, of which Mr Coombes was appointed Chief.

The division was charged with two main responsibilities: firstly, to assist the R.A.A.F. and industry in problems dealing with the manufacture and operation of aircraft—this was its main function during the war; and secondly to undertake the long-range research on fundamental problems of aeronautics on which future progress of the aircraft industry would depend. In the two years following its establishment, the Division of Aeronautics acquired scientific, technical and administrative staff, purchased or constructed its first items of equipment and trained the staff in

their use, and began its scientific and development work. It was organised into four main sections: aerodynamics, structure and materials, engines and fuels, and instruments.

Almost all experimental work in aerodynamics was carried out in wind tunnels. The usefulness of a wind tunnel depended on the principle that the force on a body moving through air was the same as that on a body held at rest in a uniform stream of air of the same speed. A small model of the aircraft being studied was placed in the tunnel and the forces in the model were measured as air, at a known speed, swept past it. In this way it was possible to obtain the general aerodynamic characteristics of the model and to study the performance, controllability and safety of an aircraft. A wind tunnel was therefore one of the first items of equipment to be installed in the new laboratory. It was designed by Dr G. N. Patterson, who came out from the Royal Aircraft Establishment, Farnborough, for this purpose.

Wind tunnels were of two main types: the straight through and the closed return tunnel. An important consideration influencing Patterson's choice of the latter was the great saving in power effected by arranging continuous circulation of air throughout the system. A small scale (one-eighth) model was first constructed and tested at the Engineering School of the University of Melbourne, where it performed satisfactorily. The large-scale tunnel had a working section 9 feet by 7 feet and a maximum air speed of 300 feet per second. The successful manufacture by Kelly and Lewis Pty Ltd of Springvale, Victoria, of the welded steel shell 105 feet long with a maximum cross section 14 feet by 18 feet, and of the wind tunnel balance, was a creditable industrial achievement.

Test runs made towards the end of 1941 bore witness to the excellence of its design. Success in the design and construction of wind tunnels was by no means a foregone conclusion; about this time three large and expensive tunnels built overseas gave a great deal of trouble owing to an unsatisfactory distribution of air flow.

Completion of the tunnel in December 1941 was most opportune, because it made possible the immediate investigation of such aerodynamic problems as were likely to result from modifying the designs of high-speed military aircraft then being manufactured or about to be manufactured in Australia. The C.A.C. made extensive use of it in developing four new designs of aircraft.

At times the wind tunnel was operated 16 hours a day, and it would have been run 24 hours a day if more staff had been available. Numerous investigations, many of them prompted by the thought that Australia might be cut off altogether from outside supplies, were undertaken. Some of the many modifications made to the Beaufort bomber, such as the installation of more powerful gun turrets, were important enough to require checking in the wind tunnel.

Tests were made not only to assist in the design of new aircraft but to solve the problem of how to reduce the loss of speed occasioned by such

attachments as jettison fuel tanks and radar aerials. Tests were also made on the stability of rockets, bombs and torpedoes. Supply-dropping parachutes, towed targets, and many other devices, were the subject of wind-tunnel experiments.

Studies made in the course of designing the wind tunnel itself opened up new avenues of investigation in the design of ducts and fans. Thus considerable help was given by the wind-tunnel experts in solving problems related to cooling the completely-enclosed engines of the Australian cruiser tank, and to the flow of air in food dehydration plants. They were also able to help in improving the ventilation in mines and factories.

Towards the end of the war, as the pressure of *ad hoc* investigations eased, the wind tunnel began to be used for fundamental research in the fields of boundary layer, flow compressibility and turbulence, with a view to its application to the higher flight speeds promised by jet aircraft, then in the early stages of their development.

Under the guidance of Dr Woods,[3] the Engines and Fuels Section of the laboratory became the centre for testing internal combustion engines of all types. Performance tests on the engine of a bomber, for example, made it possible to alter the technique of operating the engine in such a way as to increase the range of the aircraft. The formulation of specific instructions for operating engines so as to obtain maximum range for the aircraft was a problem that received much attention from the section.

Early in 1942 the R.A.A.F. became very worried about the excessive wear occurring in aero-engine cylinders, not only in operational areas but also on training airfields. Losses from this source grew to such proportions that it was almost impossible to keep up with replacements. The trouble was discovered to arise mainly from the entrance of dust into the engines. In many areas, especially those inland where there was little or no grass on the airfields and conditions were excessively dry, training aircraft when taking off would raise such clouds of dust, often rising to 2,000 to 3,000 feet, that during their circuits they would scarcely ever leave the dust-laden zones.

The Aeronautical Laboratory approached this problem from several angles. First it looked into the question of speeding the manufacture of cylinders. Ordinarily, fins of air-cooled cylinders were machined out of a solid forging of high-quality steel, and in the course of boring and turning operations about 90 per cent of the metal was cut away. This was not only waste of a valuable material always in short supply, but a time-consuming and expensive process. A method was worked out whereby fins were furnace-brazed with copper on to the steel barrel. By placing the fins much closer together than could be done by machining them, and by making them of a material of high thermal conductivity, a greater output could be obtained from the cylinder. Unfortunately, by the time the new

[3] M. W. Woods, BE, BSc, DPh. Research Fellow in Engineering, Univ of Melb, to 1940; Officer-in-Charge Engines and Fuels Section, Aeronautical Research Labs, 1940-50. Of Melbourne; b. Hobart, 19 Nov 1911.

technique had been proved, the production of cylinders by the ordinary method had grown to such a scale that it was deemed wiser not to interfere with the manufacturing process. Nevertheless, because of its unusually high capacity for heat dissipation, the composite cylinder had distinct possibilities for high-speed engines and it was with some satisfaction that the division learned later that cylinders of a similar kind had been evolved in the United States.

Another method of coping with the problem of excessive wear was to build up the worn parts of cylinders by electroplating them with chromium. Experience in the United States suggested that if this procedure were adopted it would be necessary to form a porous deposit of chromium to ensure adequate lubrication. Australian tests with hard chromium plating appeared to give equally good results. The Aeronautical Research Laboratory, in collaboration with the Munition Supply Laboratories, improved the technique of chromium plating to the point where the life of a reclaimed cylinder was equal to that of the original cylinder.

Neither of these attacks on the problem could hope to provide more than temporary relief; neither went to the root of the matter, which was to devise some means of preventing dust from entering the engines.

Before this could be done it was necessary to learn something about the dust itself. An officer of the division was sent to a large number of Australian airfields to collect samples, which were brought back and analysed for the distribution of particle size. As a result of these measurements large quantities of an experimental standard dust were made representing the average kind of dust from Australian airfields. This dust was fed to working engines protected with different kinds of filter, and the efficiency of the filters was carefully studied. The work was exceedingly slow and laborious but yielded results of great practical interest and usefulness.

In view of the fact that Australia produced no aluminium—in 1939 there were no facilities even for fabricating ingot aluminium—the Division of Aeronautics, in cooperation with the Division of Forest Products, worked hard (*a*) to discover species of Australian timber suitable for aircraft construction, both in the form of solid timber for spars and booms and as veneers for plywood; and (*b*) to produce design data for aircraft structures of Australian timber and to develop new techniques for fabricating timber. The Wood Technology Division of the New South Wales Forestry Commission also took part in this work, concentrating mainly on a study of the physical properties of coachwood for the Mosquito aircraft.

Most of the available information concerning aircraft designs in timber related to imported materials, so that it was necessary, having discovered the physical properties of Australian timbers, to modify the designs to suit the new materials. In Victoria attention was paid chiefly to the possibility of making in hoop pine and mountain ash the equivalents of major metal components for the aircraft then in production. One of the more conspicuous successes in this work was the redesign in mountain ash of the

tail plane of the Beaufort, which proved to be both stronger and lighter than the original tail plane. Another was the production of light-weight panels consisting of a grid of light members as a sandwich between two plywood faces. These, when used in the floors of transport aircraft, led to a useful saving of weight.

Another ingenious use of wood was for special light fuel tanks which could be jettisoned when empty and which helped to increase the range of Kittyhawks, Lightnings and Boomerangs: thin wood veneers bonded with synthetic resin were moulded in an autoclave under heat and pressure. Once the many difficulties encountered in the gluing process had been overcome, their manufacture on a large scale represented a considerable saving of light metal alloys.

The failure of a twin-engined wooden training plane in the air during 1941 led to a thorough examination of the causes of failure in glued joints. In the course of investigations of the strength of aircraft timbers the important discovery was made by the C.S.I.R. Division of Forest Products that at a given moisture content strength decreased very considerably with increase of temperature. This characteristic of timber had not before been recognised.

Apart from these last few examples, only limited use was made of the large amount of investigational work done on the use of wood in aircraft. Its value as an insurance against the loss of supplies of light metal was unquestioned. At one critical period of the war the stocks of aluminium ingot in Australia sank to the alarmingly low figure of 10 days' normal consumption.

For some time after the production of military aircraft had begun in Australia, there was no proper organisation for the conduct of acceptance tests on new types of aircraft. Consultations between the C.S.I.R., the Aircraft Production Commission and the R.A.A.F. led to the Air Board's setting up a flight known as the Special Duties and Performance Flight. Schedules of flight tests drawn up by the Division of Aeronautics were used for trials on the Wackett bomber type CA-4, the Wackett trainer, the Boomerang, the Australian Beaufort, the De Havilland Dragon and the De Havilland troop-carrying glider.

Failure of aircraft in service arose from many causes, prominent among which were fatigue (caused by repeated stressing) and corrosion. Failure due to fatigue of the structure or of smaller components such as airscrew blades or engine parts sometimes caused serious accidents. Instances of this kind of failure were investigated by the laboratory, as also were failures due to corrosion. One of the more difficult problems that came to the laboratory concerned the corrosion of the cooling systems by glycol-water mixtures. At one period, corroded cooling systems led to the grounding of many aircraft. Even in the leading oversea laboratories knowledge of the causes of corrosion from this source was at the lowest empirical level; indeed, Australian investigations revealed that two substances marketed

as inhibitors of corrosion were in fact liable to increase it. Some of the corrosive action of these cooling mixtures was traced back to the presence in them of small amounts of dissolved copper.

Testing the strength of aircraft wings and other components, an indispensable activity in any aeronautical research laboratory, called for much mechanical ingenuity and improvisation. This section, which was under the leadership of Mr Wills,[4] devised a method for applying, rapidly and automatically, repeated loads to a large structure, such as the wing. Wings of Australian-built Mosquitos were tested to destruction. This was the first time in any country that such tests had been applied to so large a component. An account of this work was read by Wills at the Anglo-American Aeronautical Conference held in New York in May 1947. Commenting on this and other work done in Australia, the editorial of the British journal *The Aeroplane* stated:

> His (Wills') country has a population which could be housed in London or New York, yet its aeronautical research establishment had made further progress in fatigue testing of complete aircraft wings than either Britain or the United States, an eloquent reminder that achievement comes from selecting the right goal and being single-minded in pursuit of it.

It was very important for a designer to know the distribution of stress in an aircraft, but it was difficult to measure it with mechanical strain gauges. The electric wire resistance gauges which were becoming available from overseas at about this time opened up great possibilities in the study of distribution of stress in complex structures, but needed considerable modification for particular purposes. A great deal of work was done in the Division of Aeronautics to perfect the local manufacture and application of electric strain gauges. Stresses in gun mountings during firing, and in engine mounts, wings and the forces in aircraft controls during flight manoeuvres, were all studied with this type of gauge.

Examination of captured enemy equipment was another of the laboratory's activities. A careful study of the alloys being used by the enemy, for example, indicated that he was seriously short of some alloying elements. It also disclosed that some interesting metallurgical progress had been made. An aluminium alloy containing an unusually large proportion of zinc, taken from Japanese air frames, was found to have a strength-to-weight ratio superior to that of any alloy used by the Allies. Numerous components of enemy aircraft were examined. Special attention was given to the performance of aircraft engines. This work was a great help to Allied intelligence services since it avoided the delay of shipping the equipment to Britain or the United States for examination. The American Air Force in particular made extensive use of the wide range of facilities provided by the Division of Aeronautics.

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[4] H. A. Wills, Research Officer, then Deputy Chief Superintendent, Division of Aeronautics and Aeronautical Research Labs. Of Melbourne; b. Boulder City, WA, 16 May 1906.

The great speeds at which the crankshafts and propellers of aircraft rotated, and the high loads and temperatures which occurred in the main bearings and piston rings, necessitated the development of special alloys for bearings and the expenditure of much effort on research into the origin of friction between sliding surfaces. The development and selection of a bearing metal with the correct mechanical, physical and frictional properties was a highly technical matter and one upon which much care had to be lavished, since small variations in the composition and structure of the bearing alloy could have a profound effect upon its performance. The correct procedure in making a bearing was also of first importance.

Initially all major aircraft bearings were imported, but as time went on supplies from overseas became so uncertain that the aircraft industry was obliged to undertake their local manufacture. Fortunately for industry, the C.S.I.R. had established a section for the purpose of studying problems associated with friction, wear, lubricants and bearings.[5] It so happened that just before the outbreak of war, Dr Bowden, an Australian physicist working at Cambridge, widely known for his work on friction and lubrication, was on a short visit to Australia, and the opportunity was taken of enlisting his services in the establishment of the new section. Bowden quickly got together a team of physicists, chemists and engineers, and using the experience he had gained in England directed the construction of equipment for use in studying problems that were likely to arise. In this he was greatly helped by the University of Melbourne, which not only provided accommodation in its Chemistry School but also, through the Engineering School, provided workshop facilities.

The two bearings of greatest interest to the Australian aircraft industry during the war were the silver-lead-indium bearing used in the Wasp engine, and the copper-lead bearing used in the Rolls Royce Merlin engine.

For some months the first stage in the manufacture of the silver-lead-indium bearing seemed to be beyond the capacity of the local manufacturers. The section immediately came to their aid by working out a technique of centrifugal casting, full details of which were communicated to the manufacturers, A. Wassilief Pty Ltd. It went further and constructed the complete bearing, electroplating on the layer of silver a film of lead and finally a film of indium. This, the first aircraft bearing to be made in Australia, went into service in a Wirraway shortly after it had passed its engine tests.

The work on bearings soon assumed such importance that a Bearing Control Committee was formed, comprising representatives of the R.A.A.F., the Department of Aircraft Production and the C.S.I.R., under the chairmanship of Group Captain Armstrong.[6] Its function was to co-ordinate all work on bearings and to provide liaison between the research laboratory and industry. As an additional link in this chain, the Department of Aircraft Production set up a Pilot Bearing Annexe to work in

[5] The decision to establish the section was taken in Nov 1939; work began in Jan 1940.

[6] Air Cmdre W. S. Armstrong, CBE, BSc. Director of Production, RAAF, 1937-43; Director of Tech Services 1943-47. Of Camberwell, Vic; b. Melbourne, 4 Jan 1904.

close association with the C.S.I.R. The general procedure was to make a prototype bearing in the C.S.I.R. laboratories, to try out the method of making it on a larger scale in the Pilot Bearing Annexe, and when it was known to be successful to hand over the technique to the local bearing manufacturers.

In this way all the main bearings required in the wartime aircraft industry were pioneered. Bowden and his colleagues found time, especially towards the end of the war, to investigate the theory of the action of bearing metals, and through a study of different bearings, especially the copper-lead bearing of the Rolls Royce Merlin engine, they were able to make important scientific contributions to the subject.[7]

In pioneering a field of research new to Australia, the Lubricants and Bearings Section provided an excellent example of the mutual fructification of theory and practice. A practical instance of their work was the ingenious method developed for studying the lubrication between the piston ring and cylinder wall of a running engine and of the lubrication in a journal bearing. It depended essentially on measuring the electrical resistance of the film of lubricating oil while the engine was in motion; for full fluid lubrication the resistance was high, but if the film was reduced in thickness to molecular dimensions (thus giving rise to boundary lubrication) or broke down altogether,[8] a pronounced drop in electrical resistance took place. One of the most striking results that emerged from this investigation was the discovery that direct metallic contact between cylinder wall and piston ring could not be completely eliminated. Even with the best lubricants intermittent rupture of the lubricant film occurred, with consequent metallic seizure and wear. Many other results of theoretical interest as well as of practical importance were obtained by using this technique, but too late to have any bearing on wartime manufacture of aero-engines.

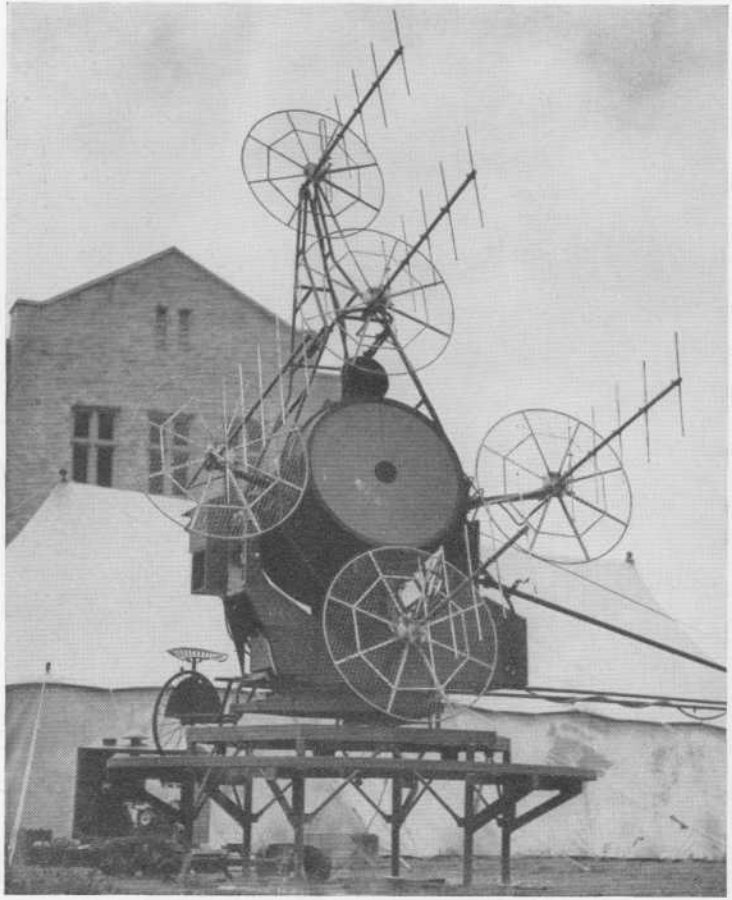
The second of Wimperis's recommendations was put into effect just before the war, with the setting up of a Department of Aeronautical Engineering at the University of Sydney under Professor Stephens,[9] who was appointed to the chair in 1939.[1] A four-year course in aeronautical engineering was established and the first students were enrolled in 1940. The object of the course was to provide a general education in the fundamental principles of engineering with as much specialisation in aeronautical subjects as the university was able to provide. As the department was part of a Commonwealth scheme, arrangements were made to allow students who had completed the first two years of a recognised engineering

[7] F. P. Bowden, "The Physics of Rubbing Surfaces", *Journal and Proceedings of the Royal Society of NSW*, Vol. 78 (1944), p. 189.

[8] The technique could not enable a distinction to be drawn between these two conditions; that is, the resistance was low in both circumstances.

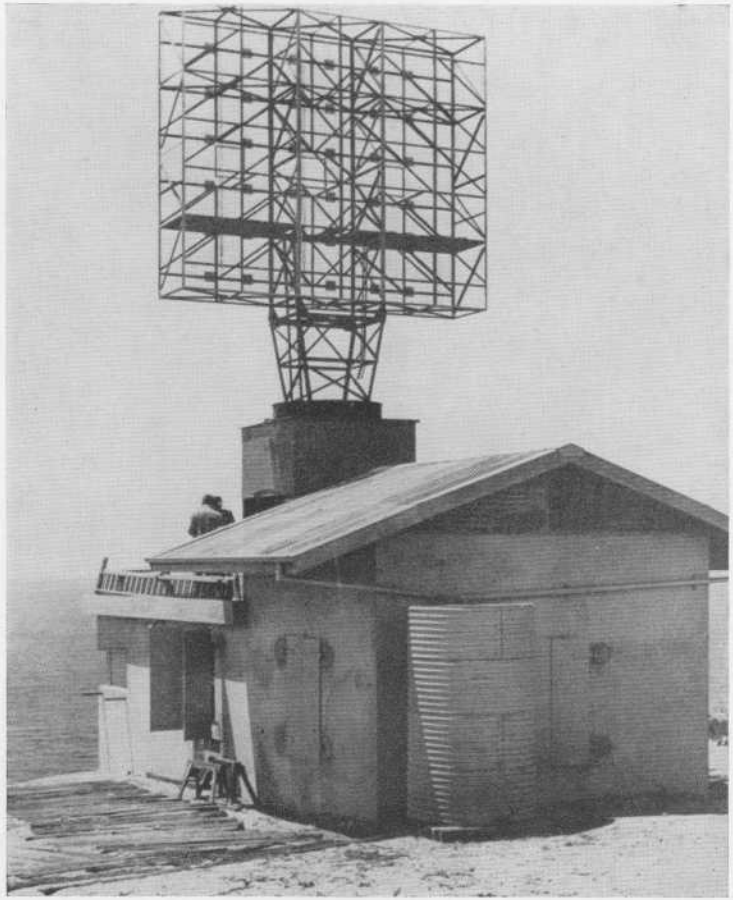
[9] A. V. Stephens, MA. Scientific officer, Royal Aircraft Establishment, Farnborough, Eng, 1930-34; Fellow St John's College, Cambridge, 1934-39; Prof of Aeronautics, Univ of Sydney, since 1939. B. Epsom, Surrey, Eng, 9 Jul 1908.

[1] Some instruction in aeronautical subjects had been given in the Univs of Melbourne and Sydney before this, but this was the first chair of aeronautics to be established in an Aust university.



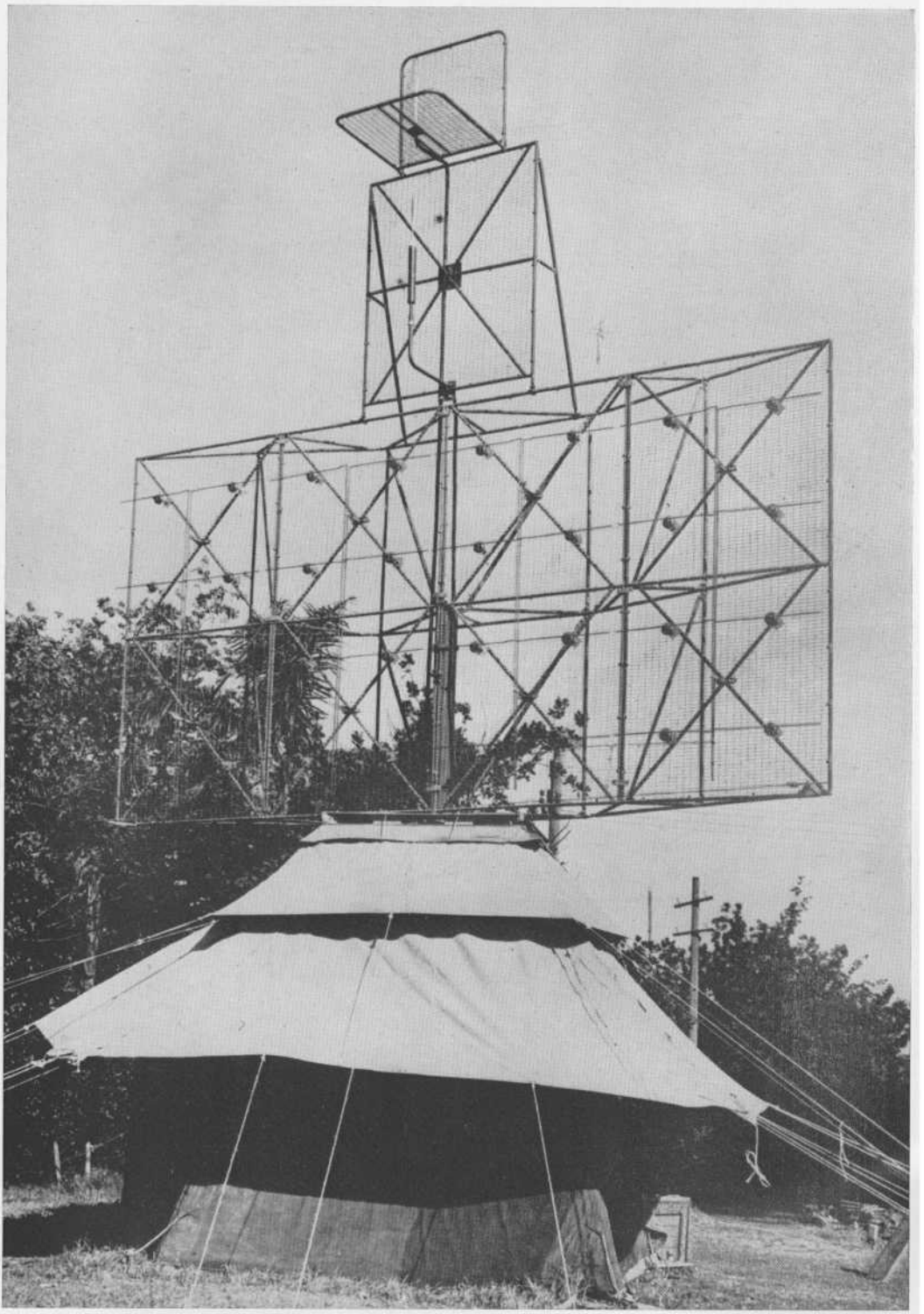
(*Radiophysics Laboratory*)

Searchlight control equipment.



(*Radiophysics Laboratory*)

Shore-defence radar equipment at Dover Heights, near Sydney.



(Radiophysics Laboratory)

Light-weight air-warning equipment.

course in any other Australian university to enter the third year at Sydney and to proceed to the degree of Bachelor of Engineering in aeronautics. In the first years of its existence the department's research concentrated mainly on aerodynamics and its application to problems of design, together with the more general aspects of aeronautical engineering. A modern type of wind tunnel 7 feet by 5 feet was installed and was used in the development of a troop-carrying glider for the De Havilland Aircraft Company.

The third of Wimperis's recommendations, namely the formation of a body to advise on aeronautical research in Australia, was not put into effect until some progress had been made with the first two. Towards the end of 1941 a stage had been reached that warranted taking the third step, and the Prime Minister accordingly established the Australian Council for Aeronautics.[2]

The Australian council advised the Government on scientific and technical matters relating to the development of the aircraft industry; it advised the C.S.I.R. on the investigations it considered should be initiated, and the universities and technical colleges on matters relating to education in aeronautics. It also rendered a valuable service in collecting and disseminating information from overseas and publishing reports on work done at the University of Sydney and at Fishermen's Bend.[3]

When a pilot made a sharp turn at a high speed, momentary "blackout" might occur. The pilot would experience unusual visual disturbances such as a blue haze followed rapidly by a sensation of intense blackness which ended in a momentary loss of consciousness. These visual effects were correlated with the marked centrifugal force developed during high-speed turns. As the maximum speed of aircraft continued to increase, instances of blackout became more numerous and they were recognised as a major hazard in high speed flying. Individuals varied in the acceleration they could withstand before blacking out. Briefly, it was generally believed to be due to the fact that centrifugal force drove the blood from the higher to the lower regions of the body, especially to the abdominal area, with the result that insufficient blood reached the brain. Nerve cells thus deprived of oxygen no longer responded to the stimulus of light.

One of the first Australian scientists to become interested in this phenomenon was Professor Cotton.[4] His attention was drawn to it almost accidentally by a reference in an evening newspaper. Some years earlier he had made an extensive study of the location of the centre of gravity in the human body and had for long been deeply interested in the circulation of the blood. Quite early he formed the opinion that any device likely

[2] The members of the council were: Sir George Julius (Chairman), Gp Capt W. S. Armstrong, W. E. Bassett, A. G. Berg, I. H. Boas, L. P. Coombes, N. A. Esserman, A. Murray Jones, J. T. McCormick, F. J. Shea, Prof A. V. Stephens, J. Storey, Air Cmdre E. C. Wackett, L. J. Wackett, H. A. Wills, and B. McA. Foster (Secretary).

[3] The Australian Aeronautical Council series, beginning with *The Inauguration of the A.C.A.* (1944).

[4] F. S. Cotton, DSc. Lecturer in Physiology, Univ of Sydney, 1913; Senior Research Fellow of National Health and Medical Research Council 1939-45; Research Prof of Physiology, Univ of Sydney, 1941-55. B. Sydney, 30 Apr 1890. Died 23 Aug 1955.

to counteract blackout would have to depend for its success on maintaining blood circulation throughout the body. More specifically, a successful device would have to ensure maintenance of the blood return from the lower portions of the body to the heart. Cotton believed that once it was returned to the heart, that organ would have sufficient margin of power to pump the blood to the brain against the centrifugal force.

Cotton's solution to the problem of maintaining the circulation of the blood was the "aerodynamic anti-G suit".[5] This consisted of a series of overlapping rubber sacs incorporated in two separate leggings and a pair of shorts.[6] The leggings extended from the soles (or from the ankles in some modifications) nearly up to the top of the thigh. The thigh portions of the shorts were arranged to overlap the leggings. Each legging contained four rubber sacs; the shorts contained two, the lower one covering the lower part of the abdomen and the upper one extending to the lower borders of the ribs. Each rubber sac was so arranged that when inflated an inextensible fabric in its outer wall prevented it from expanding outwards, while the rubber coating on its inner wall allowed it to expand and press smoothly against the skin. The rubber sacs did not inflate until the body was subjected to moderate accelerations, and then the pressure was so regulated that it increased in proportion to the acceleration. This automatic regulation of pressure was attained by means of a valve. In the design and fabrication of the rubber portions of the suit Cotton received much help from Dunlop Rubber Australia Ltd.

To determine the efficacy of the suit in the laboratory, it was necessary to devise some way of exposing a test subject to high accelerations, that is to high values of G.[7] This was most readily, if not most comfortably, done by whirling the subject in a centrifuge—an ordeal from which even experienced pilots were known to shrink.[8] Funds for building the machine were provided by the R.A.A.F. Flying Personnel Research Committee and the National Health and Medical Research Council of Australia.

From the middle of 1941 onwards a considerable body of data gained by experiments on pilots and trainees made it possible to assess fairly accurately the amount of protection afforded by the suit against increasing accelerations.[9] It was found that the suit increased a pilot's tolerance to high accelerations by about 30 per cent; in other words, if without a suit the maximum acceleration that could be tolerated by a pilot without loss of vision was 6 G., with the suit he could tolerate 8 G. The average pilot "blacked out" for several seconds when exposed to about 5 G. or 6 G. In a test carried out just before he left on a mission to Canada and the

[5] F. S. Cotton, "An Aerodynamic Suit for the Protection of Pilots against Blackout", *Aust Journal of Science*, Vol. 7 (1945), p. 161.

[6] Originally it was intended to make the suit in one piece, but the problem of making it to fit pilots of different sizes and builds was considered too difficult of solution at that stage.

[7] 1G is the acceleration due to the earth's gravitational field. Other accelerations are measured in terms of it.

[8] Sqn Ldr K. V. Robertson, chief test pilot for this work, played the part of guinea pig most successfully and patiently, both in the air and in the centrifuge.

[9] Mr C. W. W. Prescott was chiefly responsible for the design of the centrifuge, which was constructed by White Elevators of Sydney under the general supervision of the University Engineer, Mr T. Wilkins.

United States, Cotton was, while clad in the anti-G suit, exposed to about 9 G. (7 G. at the head and 11 G. at the feet) for 35 seconds, without blacking out. He was able to report this successful test in Canada and America and to convince the authorities there of the value of his aerodynamic suit.

By the time Cotton reached Canada, Wing Commander R. Franks of the Banting Institute of Toronto had reached an advanced stage with his independently conceived solution to the blackout problem. Franks' hydrostatic suit, so called because pressure on the pilot's limbs was exerted by water-filled sacs, was the first suit devised that afforded protection against blackout. Cotton freely communicated his ideas and experimental results to Americans working on the subject, and from then on the suit was developed rapidly, though not without a great deal of additional experimental work. The Americans quickly realised its potentialities and explored them with great thoroughness.

While the suit was being developed in the United States, further work was being done on it in Australia. Improvements were made in the local suit, especially to the valve regulating the air pressure. The valve as designed by Cotton worked easily and accurately enough, but required more compressed air than could be conveniently carried in an aircraft. A more economical, and very ingenious valve was subsequently invented by Dr Myers of the National Standards Laboratory. To comply with air force requirements the suit had to be easily donned and doffed, reasonably comfortable to wear, light and lasting, and as nearly fireproof as possible.[1] Once it met these requirements the suit was officially adopted and a wing of the R.A.A.F., under the command of Group Captain Caldwell,[2] was trained in its use. The wing was based on Darwin, but to the disappointment of the pilots they were unable to meet the enemy in combat, for at this very juncture the Japanese attacks on Australia ceased.

In the meantime large centrifuges were built in the United States, and from the information obtained with their aid the United States Navy and Army had devised, by 1944, an anti-blackout suit, provided with a series of bladders inflated to appropriate pressures by a valve operated automatically (as in the Australian types) by gravity and the centrifugal force at the moment.

Suits of this type were worn in ten major engagements from Palau to the Philippines, when 243 aircraft were destroyed and 75,000 tons of Japanese shipping were sunk.

At the time of the Japanese attack on Pearl Harbour the first Beaufort bombers were coming off the production line; the Wirraway and Tiger

[1] F-Lt G. C. Ellis did much to solve the problems of installation in the aircraft. Messrs A. Martin and E. Smith, technicians in the Dept of Physiology, also made useful contributions to the work of developing the suit.

[2] Gp Capt C. R. Caldwell, DSO, DFC. Successively bank officer, jackeroo, and motor trader 1928-40; served RAF and RAAF 1940-46; notable fighter pilot whose record earned him title of "Killer"; Managing Director, Falkiner, Caldwell Pty Ltd Sydney, since 1946. B. Sydney, 28 Jul 1910.

Moth and Wackett trainers were being made in substantial numbers but no attempt had been made to manufacture fighter aircraft of any kind. With the new turn of the war the question of future aircraft production was thoroughly discussed at a meeting between representatives of the Department of Air, the Department of Aircraft Production and the Commonwealth Aircraft Corporation. The Deputy Chief of the Air Staff made it clear that fighter aircraft capable of intercepting bombers launched from any Japanese aircraft carriers that might attack Australian capital cities and other industrial centres, were urgently needed. He strongly advocated that every effort should be made to procure P-40 (Kittyhawk) fighters from the United States and that at the same time an attempt should be made to manufacture a fighter locally as an insurance against the non-arrival of the Kittyhawks.

The C.A.C. had already considered an aircraft of this type, and had in fact designed one which it believed would have the high rate of climb and easy manoeuvrability needed for an effective interceptor fighter. The aircraft under consideration, a low-wing monoplane which subsequently became known as the Boomerang, was essentially an adaptation of the Wirraway.[3] Indeed Wirraway parts constituted about 65 per cent of the aircraft. With wind tunnel tests as a guide the Chief of the C.S.I.R. Division of Aeronautics formed the opinion that the adaptation proposed by the C.A.C. was an excellent method of building, in a reasonable time, a substantial number of high-performance aircraft. After some further improvements had been made to the design there seemed every prospect of attaining a maximum speed of 300 miles an hour at 15,000 feet, with a rate of climb of 2,560 feet per minute.

Acting on the joint recommendation of the Minister for Air and the Minister for Aircraft Production, the War Cabinet decided on 2nd February 1942 to place an order for 105 Boomerangs, although not even a prototype had been built. Since it had been decided to cease making Wirraways for the time being, there would be ample facilities for the new project. In fact the C.A.C. was faced with the alternatives of making the new fighter or of continuing with making the Wirraway beyond the real needs for this aircraft, or of dismissing 2,000 experienced aircraft workmen with little prospect of securing their services again when they were wanted.

Since the forecast performance of the Boomerang was only about that of the Buffalo (an American aircraft equipped with the same class of engine), which had not achieved much success against Japanese Zeros in Malaya, there was naturally some hesitation on the part of the Government about going on with the Boomerangs while there was still the possibility of importing more modern fighters. These prospects became so un-

[3] Some of the important characteristics of the Boomerang were as follows:

Wing area	225 sq ft	Diving speed (max)	410 mph
Wing span	36 ft	Rate of climb	2,500 ft per min
Top speed (at 15,000 ft)	300 mph	Range on 180 gal of fuel	500 miles

The aircraft was fitted with a Pratt and Whitney twin-row Wasp engine of 1,200 h.p., equipped with a 2-speed supercharger.

certain that the Boomerang was put into production and the first was flown on 29th May 1942.

The Department of Air arranged for comparative trials, taking the form of mock combats, to be carried out between the first Boomerang and the Kittyhawk and Airacobra. Comparative figures for the performance of the aircraft are shown in the accompanying table.

Altitude	Boomerang	Kittyhawk	Airacobra
	Performance in level speed (m.p.h.)		
G.L.	260	280	315
5,000	280	300	340
10,000	295	320	360
15,000	295	315	360
20,000	300	310	330
25,000	285	295	325
30,000	260	275	310
	Performance in climb, ft per min.		
G.L.	2,500	1,850	2,000
5,000	2,500	1,850	2,000
10,000	2,300	1,850	2,000
15,000	2,080	1,400	1,550
20,000	1,550	1,000	1,100
25,000	1,050	550	650
30,000	500	150	200
Service ceiling	34,000	30,500	31,500

In a report on the trials it was stated:

At 10,000 feet

The Boomerang is more manoeuvrable than the Kittyhawk and can turn inside it. The Kittyhawk's speed advantage is not sufficient for it to dictate the type of combat and, although it gains more in the dive, the Boomerang's greater manoeuvrability with pull out and superior climb finds it level with the Kittyhawk at the top of the ensuing zoom. The Kittyhawk's only manoeuvre is to dive through a great height and break off the combat; the speed advantage is not sufficient for it to fly away at the same height without becoming vulnerable once combat is joined with the Boomerang.

The Airacobra has a greater speed advantage over the Boomerang than has the Kittyhawk but is outmanoeuvred at the same height in concentric attack (turning circles). When first attempted the Airacobra was able to dictate terms of combat to the Boomerang by its superiority in dive and zoom which allowed it to gain the extra height necessary to deliver an attack from above. Later this advantage was not so apparent and this was thought to be due to the pilot becoming more familiar with the Boomerang.

When the C.A.C's attempt to build a dive bomber of its own design became involved in unforeseen difficulties[4] and the making of Wirraways was suspended, it was decided to concentrate efforts on the Boomerang and the order was increased to 250. The production schedule of the Wirraway, the Wackett Trainer and the Boomerang is shown in the accompanying table.

[4] There was little scope for such a bomber in New Guinea and the islands: it was hard enough to find the enemy in the jungles and mountains, let alone dive-bomb him.

		Wirraways		Wackett Trainers	
		Per month	Cumulative	Per month	Cumulative
1939	Jul	2	2		
	Aug	4	6		
	Sep	6	12		
	Oct	7	19		
	Nov	6	25		
	Dec	8	33		
1940	Jan	5	38		
	Feb	8	46		
	Mar	5	51		
	Apr	6	57		
	May	11	68		
	Jun	7	75		
	Jul	8	83		
	Aug	16	99		
	Sep	15	114		
	Oct	33	147		
	Nov	34	181		
	Dec	23	204		
1941	Jan	5	209		
	Feb	9	218		
	Mar	21	239	1	1
	Apr	22	261		
	May	19	280	3	4
	Jun	20	300	9	13
	Jul	5	305	7	20
	Aug	26	331	13	33
	Sep	36	367	23	56
	Oct	45	412	14	70
	Nov	37	449	10	80
	Dec	42	491	16	96
1942	Jan	25	516	22	118
	Feb	22	538	35	153
	Mar	29	567	29	182
	Apr	26	593	18	200
	May	18	611		
	Jun	9	620	Boomerangs	
	Jul				
	Aug			1	1
	Sep			3	4
	Oct			5	9
	Nov			4	13
	Dec			11	24
1943	Jan			3	27
	Feb			13	40
	Mar			21	61
	Apr			18	79
	May			16	95
	Jun			10	105
	Jul			4	109
	Aug			22	131
	Sep			14	145
	Oct			7	152

		Wirraways		Boomerangs	
		Per month	Cumulative	Per month	Cumulative
1943	Nov	5	625	9	161
	Dec	5	630	8	169
1944	Jan	—	630	4	173
	Feb	—	630	5	178
	Mar	4	634	6	184
	Apr	5	639	12	196
	May	8	647	5	201
	Jun	3	650	5	206
	Jul	1	651	6	212
	Aug	4	655	5	217
	Sep	6	661	2	219
	Oct	8	669	4	223
	Nov	9	678	5	228
	Dec	8	686	7	235
1945	Jan	2	688	13	248
	Feb	7	695		
	Mar	2	697		
	Apr	6	703		
	May	4	707		
	Jun	3	710		
	Jul	5	715		
	Aug	2	717		
	Sep	5	722		
	Oct	2	724		
	Nov	5	729		
	Dec	4	733		
1946	Jan	3	736		
	Feb	3	739		
	Mar	5	744		
	Apr	1	745		
	May	7	752		
	Jun	2	754		
	Jul	1	755		

Boomerang aircraft performed valuable service with forward operational units of the R.A.A.F. in New Guinea and in the Solomons, where they were used for such varied army cooperation work as marking targets for fast bombers, dropping mail and supplies to troops, dive-bombing targets inaccessible to other aircraft, and also for mapping and photographic reconnaissance flights.

The Commonwealth Aircraft Corporation was the only section of the Australian aircraft industry that undertook original development work during the war. Its design section worked on several new types of aircraft besides the Boomerang. In June 1940 the War Cabinet voted the corporation a sum of £50,000 for the construction of a prototype light bomber-reconnaissance aircraft. The resulting aircraft, known as the Wackett bomber, was completed in 1941.

Only after intensive performance tests and modifications had been made did the War Cabinet, early in 1942, authorise the production of 105 of these aircraft. Even then further modifications to the prototype

were made before the design was approved for production, by which time the order had been reduced to 20. The design of the aircraft called for as much in the way of imported materials as did the Beaufort. Furthermore, no engine then being made or even planned for manufacture in Australia was suited to it. In these circumstances it probably came as no surprise to the industry that after the first two bombers had been delivered, in September 1944, the whole project was closed down and the staff transferred to making the Mustang.

The War Cabinet also gave approval for the development of a new type of fighter aircraft (the CA-15 Fighter) designed for medium altitude operation and to be complementary to the Mustang, which operated at high altitudes. When the prototype was tested, its performance proved in many ways superior to that of the Mustang. The CA-15 was, in fact, a much greater technical achievement than the Boomerang, but by the time it had passed through the long period of experiment and development the war had ended and there was no need for it.

A proposal to manufacture the Beaufighter, the fastest low-altitude, twin-engined, long-range fighter aircraft that Britain had produced, was first made in 1941 by Storey soon after he had returned from three months' visit to England. The Beaufighter was suitable either for concurrent manufacture with the Beaufort bomber, or as its successor, since about 75 per cent of the components and manufacturing techniques were common to both aircraft. For several reasons the proposal to manufacture the Beaufighter was temporarily abandoned and not revived until November 1942.[5] By then the problem had arisen of what to do with the facilities that would become available once the Beaufort program was complete. As soon as the end of this program was in sight approval was given for manufacture of the Beaufighter to begin.

Designed by the Bristol Aeroplane Company, the Beaufighter was a most versatile aircraft, capable of delivering low-level attack by torpedo, cannon or rocket bomb. It had a maximum speed of 304 miles an hour at 9,500 feet; with an all-up weight of 24,650 pounds the aircraft had a rate of climb of 830 feet per minute from sea level to 7,200 feet and of 540 up to 14,500 feet.[6] Wind tunnel tests carried out by the Division of Aeronautics indicated that it might be necessary to fit a dihedral tail plane in place of the straight tail plane originally fitted. Flight trials verified this prediction; the aircraft was not sufficiently stable, a defect easily remedied by making the modification foreshadowed from the wind-tunnel tests. The other principal alterations made to the British model were in the armaments: two .5-inch Browning guns were introduced in

[5] One of the reasons was that Britain herself would not be interested in any Beaufighters surplus to Australian requirements since Mosquitos were likely to replace them.

[6] Other characteristics of the aircraft were:

Span	57 ft 10 in	Carrying 500-lb bombs with flame-damping exhausts fitted and with a normal fuel load of 700 gal, the range was	570 sea miles
Length	41 ft 4 in		
Overall height	15 ft 10 in		
Wing area, net	451 sq ft		
		Service ceiling	28,900 ft

One 500-lb bomb was carried under each wing; alternatively a 2,000-lb bomb or mine beneath the fuselage; or a 200-gal auxiliary fuel tank.

each wing, replacing .303-inch guns, and a rearward firing gun of greater range was installed.

The deliveries of Beaufighters and of Beaufort bombers are shown in the accompanying table.

		Beauforts		Beaufighters	
		Per month	Cumulative	Per month	Cumulative
1941	Aug	1	1		
	Sep	1	2		
	Oct	3	5		
	Nov	2	7		
	Dec	3	10		
1942	Jan	4	14		
	Feb	6	20		
	Mar	8	28		
	Apr	12	40		
	May	16	56		
	Jun	20	76		
	Jul	13	89		
	Aug	17	106		
	Sep	24	130		
	Oct	29	159		
	Nov	25	184		
	Dec	24	208		
1943	Jan	19	227		
	Feb	27	254		
	Mar	23	277		
	Apr	27	304		
	May	24	328		
	Jun	33	361		
	Jul	33	394		
	Aug	33	427		
	Sep	37	464		
	Oct	34	498		
	Nov	32	530		
	Dec	29	559		
1944	Jan	25	584		
	Feb	26	610		
	Mar	17	627		
	Apr	11	638		
	May	20	658	1	1
	Jun	15	673	2	3
	Jul	15	688	8	11
	Aug	12	700	13	24
	Sep			20	44
	Oct			23	67
	Nov			27	94
	Dec			18	112
1945	Jan			28	140
	Feb			26	166
	Mar			28	194
	Apr			30	224
	May			29	253
	Jun			31	284
	Jul			26	310
	Aug			19	329

Eighteen months after the decision to manufacture it, and 14 months after the receipt of the first batch of drawings, the first Australian Beaufighter was given its flight test. Australian rocket-firing Beaufighters were in service right up to the end of the war from New Guinea north to the Philippines and west to Borneo.

Beginning in 1929 as a sales and service organisation in Melbourne, De Havilland Aircraft Pty Ltd, a branch of the English company, gradually extended the scope of its activities until, in the late thirties—and consequent on a move of the factory to Sydney—it began to undertake the partial manufacture of aircraft, relying on importations for metal fittings and aircraft engines. For example, in 1937 it made a number of DH-83A Fox Moth single-engined cabin biplanes for use as aerial ambulances by the Bush Aid Society and the Darwin Flying Doctor Service.

Two years later the tempo of the company's activities suddenly increased with the receipt of an order from the R.A.A.F. for 20 DH-82A Tiger Moth training aircraft, which were to be fitted with imported Gipsy Major engines. This order was soon followed by others and from May 1940, when the first Moth was delivered, to August 1942 more than 1,000 of these elementary trainers were built. With the exception of the first 200 they were equipped with Gipsy engines made by General Motors-Holden's. Meanwhile, in 1941 the company was asked to design and build a special type of military glider. By 1943 eight prototypes had been delivered. This was the first design project undertaken by the Australian company.

These aircraft were a valuable contribution to the Empire Air Training Scheme. Tiger Moths were made not only for the Australian section of the Empire Air Training Scheme, but also for the South African and Southern Rhodesian sections; they were also exported in limited numbers to New Zealand, India, Burma and Indonesia. Before the last of the Tiger Moths had been delivered a start was made on the manufacture of DH-84 Dragons, twin-engined aircraft for use as wireless and navigational trainers by the R.A.A.F. and also as ambulances and transports. The company made 87 Dragon aircraft, each powered by Australian-made Gipsy Major engines.

From the technical point of view, however, the most interesting achievement of De Havilland Aircraft was the manufacture, towards the end of the war, of the Mosquito bomber. The parent company in England, long experienced in the construction of wooden civil aircraft, decided just before the war to try its hand at designing a military aircraft of the same material. Such an aircraft would, De Havilland's believed, relieve the drain on supplies of light metal which was bound to be serious in wartime. It would, moreover, make possible the use of skilled labour from woodworking trades, on which there would be fewer calls than on the metalworking trades. Certain sections of the British Air Ministry, which was sceptical of the military possibilities of wooden aircraft, opposed De Havilland's proposals. The company nevertheless persisted in its views and

eventually produced the Mosquito. The advantages of wooden construction proved, in the event, to be quite considerable.

The knowledge and experience of aircraft manufacturers had for many years been such that a poor aircraft was rarely, if ever, designed and made, but every now and then one was designed that more or less unexpectedly stood out from the rank and file in the excellence of its performance and its versatility. Such an aircraft was the Mosquito which, starting life as an unarmed intruder designed for hit-and-run raids, became successively a fighter, a fighter-bomber and a first-class photographic reconnaissance aircraft, and remained in service in all these roles throughout the war.

Some time before the outbreak of war, the possibility of constructing wooden military aircraft in Australia had been seriously considered.[7] In 1938, at the instigation of the Premier of New South Wales, Mr Stevens,[8] who had invited all government departments to submit suggestions on ways in which the State's resources might be used in the event of war, the State Forestry Commission's Division of Wood Technology began a rapid survey of the properties of timbers in New South Wales with a view to ascertaining their fitness for various defence purposes. Timbers were examined to determine their suitability for rifle furniture, artillery waggons, for aircraft construction, and as substitutes for English and Canadian timbers. In its search for substitutes the Division of Wood Technology cooperated with the Standards Association of Australia,[9] the C.S.I.R. Division of Forest Products, and the Institution of Engineers of Australia. Coachwood (scented satinwood), a tree that grows in the coastal forests of New South Wales and Queensland, showed promise as a material for aircraft plywood.

Before the C.S.I.R. entered the field of wood technology in 1928, Australia had lagged seriously behind other countries of the world in regard to many of the techniques for handling and using timber, such as seasoning, milling, preserving and gluing. In the ten years that followed the setting up of the Division of Forest Products much of this leeway was made up, especially in the development of efficient methods of seasoning timber. Indeed the background of knowledge concerning kiln-seasoning of timber built up by the C.S.I.R. and by the Forestry Commission of New South Wales was of the greatest value during the war in making it possible to meet the demands for seasoned timber. Without the progress in wood technology that took place during these years, the difficulties confronting the manufacturers of wooden aircraft would have proved considerably greater than they were, if not insuperable.

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[7] The Munitions Supply Board had planned to manufacture wooden military aircraft soon after the first world war, and had acquired plant for the purpose. However no orders for such aircraft were forthcoming and the plant was eventually sold.

[8] Hon Sir Bertram Stevens, KCMG. MLA, NSW, 1927-40; Premier and Treasurer of NSW 1932-39; Aust Repve, Eastern Gp Supply Council, India, 1941-42. Consulting accountant. B. Sydney, 2 Jan 1889.

[9] The Standards Association drew up a series of emergency standards for aircraft timbers.

After discussions had taken place between the Department of Aircraft Production and Major Murray Jones,[10] General Manager of De Havilland's, the War Cabinet gave its approval to the manufacture of the Mosquito, but only on condition that it did not involve taking skilled men from other aircraft factories. It agreed that £50,000 should be set aside to enable De Havilland's to discover what would be involved in establishing production. With the department's sanction De Havilland's sent a number of its officers to Britain and the United States and also to Canada, where plans for the manufacture of the Mosquito were well advanced. Arrangements were made for the supply of blueprints, drawings and other technical details.[1] Technical liaison with De Havilland's in Britain was established and certain essential machine tools were secured. The British firm could spare only one of their own engineers, Mr Waghorn,[2] to help in the Australian undertaking.

The difficulty of obtaining skilled manpower had reached its wartime peak by late 1942, when manufacture of the Mosquito was begun. Consequently De Havilland's were compelled to build up an almost entirely new labour force of some 600 men and women, most of whom had never been in an aircraft factory before, at a time when most of the promising recruits to this kind of work had already entered the industry. Subcontractors for manufacture were of necessity engaged in all parts of the Commonwealth, but fortunately most of those concerned with the woodwork of the aircraft were in the Sydney area. Continual shortage of labour dogged the Mosquito undertaking—not so much in the wood-working industries as in the metal trades.

Among the most interesting features of its construction was the plywood and balsa wood sandwich used to cover the fuselage. In the Australian version the plywood consisted of coachwood bonded with phenol formaldehyde resin. The technique of making plywood of this kind had been pioneered some years before by the Sydney firm of Frederick Rose. Though coachwood, the nearest Australian equivalent to Canadian birchwood, was used in the Mosquito, it was inferior to the Canadian timber in some respects, being relatively weak in shear. This necessitated redesigning portions of the Mosquito wing to permit the use of thicker plywood.[3]

The demand for coachwood was so great (it was also being used for rifle furniture) that new forests round Wauchope and Wagga, New South Wales, had to be opened up. All the routine testing of coachwood for the

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[10] Maj A. Murray Jones, MC, DFC. (Served 1st AIF.) General Manager of De Havilland Aircraft Pty Ltd, Sydney, since 1940. Aviator; of Sydney. B. Caulfield, Vic, 25 Feb 1895.

[1] The main features of the Australian Mosquito were:

Over-all length . .	41 ft 2 in	Power plant .	2 Rolls Royce Merlin engines
Wing span . . .	54 ft 2 in	Max speed .	376 mph at 22,000 ft
Wing area . . .	436 sq ft	Range . .	1,260 miles
Wing loading . .	42.5 lb per sq ft		

Some modifications to the design of the British aircraft were necessary because the Rolls Royce engines were of American make and different from those used in Britain.

[2] M. M. Waghorn. Engineer, De Havilland Aircraft Co, England, to 1942; Engineering executive De Havilland Aircraft Pty Ltd, Sydney, since 1942. B. London, 16 Nov 1917.

[3] De Havilland's took over the piano factory of Beale and Co Ltd at Annandale, NSW, and operated it to manufacture fuselages. Sydney furniture firms who made wing components were: Ricketts and Thorp Pty Ltd, front spar; F. Dickin Pty Ltd, rear spar; Bray and Halliday Pty Ltd, wing skins; Reilton and Griffin, tank doors.

Mosquito was done by the Division of Wood Technology of the New South Wales Forestry Commission. As time went on the importation of timber became easier; more and more birchwood ply from Canada was used in place of coachwood owing to its superior shear modulus. Balsa wood, a timber of unusually low density, which formed the middle of the sandwich, stabilised the plywood and prevented it from wrinkling without adding greatly to the weight of the structure. No satisfactory substitute for South American balsa wood could be found among Australian timbers, although one roughly resembling it was found in the stinging tree in New South Wales. In making some of the special joints, for example those carrying bolts, compressed impregnated (compreg) plywoods found important application.

The spars of the wings, in section, resembled a metal constructional beam. The stressed skin of the wings consisted of resin-bonded coachwood ply. All wooden joints were glued and screwed—the screws, in some cases assisted by heavy clasps, serving only to hold the wood in place until the glue had set. Casein glue, being a product in common commercial manufacture in Australia, was used for making joints, in spite of the fact that it was known to be susceptible both to moisture and to bacterial attack. Since the aircraft were likely to find service in the tropics, the manufacturers gave careful consideration to the suitability of such a glue under these conditions. However the outside of the wing and fuselage were so well protected by a water-resisting, doped fabric that no serious trouble ever arose from deterioration of glued joints. Any doubts that might have been entertained on this score were set at rest by a thorough examination of the wings of an aircraft that had seen service in the tropics for some time. It revealed that the glued joints were in remarkably good condition. Nevertheless, as soon as synthetic resin cements (phenol and urea-formaldehyde resin) came on the market through the efforts of Messrs Elliotts and Australian Drug Pty Ltd, a change over to the synthetic cement was promptly made. Besides being much safer in the tropics, synthetic cements accelerated the gluing process because they set more rapidly than casein glue. The chemical firms experienced difficulty occasionally in meeting the specifications for these cements, which were far more exacting than those for cements used in the ordinary woodworking industries.

After De Havilland's had built the first jigs and assembled the first two wings to demonstrate that the tooling was correct, assembly of wings for the Mosquito was undertaken by General Motors-Holden's in their factory at Pagewood, New South Wales. The techniques required for assembling the wooden component structures of the wings were so different from those used in the assembly of motor car bodies that the firm experienced some difficulties in the early stages. Defective glued joints discovered in seventeen of the first wings to be assembled occasioned one of the more serious delays experienced in the manufacture of Mosquitos. The ill wind that brought the defective wings did, however, blow in an unusually bountiful supply of research material for the Division of Aero-

nautics, where many wings which had been rejected for use on aircraft were most carefully and profitably tested to destruction.

The absolute reliability which was the keynote of all processes and specifications for aircraft materials contributed greatly to their cost. The Aircraft Inspection Directorate maintained a most intricate system of checks and counter-checks designed to ensure dependability of material. Manufacturers of material for aircraft construction always despatched it with an accompanying "release note" signed by one of their technical officers who accepted the responsibility of declaring that the material fully met the specifications. Similarly the aircraft manufacturer was required to be in possession of this release note before he began to use the material. The system was such that should a defect be discovered at any stage, the material in which it occurred could be traced right back through all phases of its manufacture.

Plans were made by the parent company in Britain for Mr John De Havilland to visit Australia for the purpose of flight-testing the first locally made Mosquito, which was delivered on 23rd July 1943. Unfortunately De Havilland was killed in an aircraft accident. In his stead Mr P. Fillingham, chief test pilot at De Havilland's Canadian factory, was sent out and on 11th November 1943 gave the Australian-made Mosquito a flight test.[4]

The next few aircraft came rather haltingly off the assembly line. Their progress was delayed by extensive modifications to the telecommunication equipment called for by the R.A.A.F. By May 1944 the fourth aircraft was completed and De Havilland's could then inform the Department of Aircraft Production that the performance of the Australian-made Mosquito was comparable in every respect with that of the British machine. Before the thirtieth aircraft had been produced (in December 1944) progress was further marred by two fatal accidents during test flights. While experts were of the opinion that the accidents, similar to several that befell Mosquitos in Britain, arose from failure due to high-speed flutter, they could, in the subsequent inquiry into the nature of the accidents, find nothing to substantiate this opinion.

In addition to the fighter-bomber-intruder type, De Havilland's made six photographic reconnaissance Mosquitos which played an important part in the aerial survey that preceded the invasion of the Philippines. Weeks before the Leyte landing, Australian-made Mosquitos in cooperation with American aircraft ranged far and wide over the islands on reconnaissance, bringing back photographic information.

The Mosquito was the first large, wooden, cantilever wing aircraft to be made in Australia. It will probably be the last. The high hopes that De Havilland's once held for the potentialities of wood alone, wood reinforced with plastics, and plastics, were not sustained by the record of experience. In varying degrees, but most of all with plastics, the strength

[4] Actually the first aircraft was first flown by an Australian pilot, W Cdr H. Gibson Lee, before Fillingham arrived.

of these materials was notch sensitive,[5] a failing to which metals and alloys were not so prone. This makes the record of the Mosquito all the more remarkable. It was the first modern front-line machine of all wood construction to go into service.

By 1942, when the Beaufort, Beaufighter, Boomerang and Mosquito were in production or approved for production, one of the main problems occupying the minds of those directing aircraft industry was that of matching or more than matching improvements in the performance of enemy aircraft. One method of doing this was to try to improve the performance of the four types of aircraft already in production. This proved impracticable. An alternative policy was to select the best of the proven types of aircraft in use or under development by the Allied Nations and try to make them in Australia. This was the course of action finally decided upon, and to give effect to it the Director-General of Aircraft Production and the Chief of the Air Staff recommended to the Prime Minister on 9th October 1942 that a mission representative of the R.A.A.F. and the Department of Aircraft Production should be sent overseas without delay. This proposal was accepted by the War Cabinet on 7th December.[6]

Well briefed on the nature of the aircraft required, the mission left Australia in January 1943 to visit the more important aircraft manufacturing centres in Britain and the United States. On its return, in May 1943, the mission recommended that the Mustang and Lancaster should be manufactured in Australia. As manufactured by North American Aviation Incorporated to British specifications, the Mustang was, in the mission's view, the most suitable type of high-altitude fighter aircraft.

Of the British fighter aircraft studied by the mission the only one considered as likely to compare with the Mustang's performance was the Spitfire Mark VIII. Under some conditions the advantage lay with the Spitfire, under others with the Mustang. What finally decided the mission in favour of the Mustang was its greater potentialities for improvement in performance[7] and the fact that it was relatively easy to import from America supplies of equipment needed for its production.

Beginning with the first delivery in May 1945, the C.A.C. produced 59 Mustangs before the year was out.

The mission had been asked by the Air Board to recommend, if it could, a twin-engined bomber with a range of 2,000 miles while carrying a bomb load of 2,000 pounds. It found, however, that for operations of this type four-engined aircraft were being used in Britain and the United States.

[5] The tensile strength of a piece of material, in the form of a cylinder for example, is proportional to the area of its cross section. If, when the area of this cross section is reduced by notching the cylinder or boring a hole through it, the tensile strength is reduced by an amount far greater than the proportional reduction of the cross-sectional area, such material is said to be notch sensitive. Wood suffers from this defect but not to such a great extent as plastics.

[6] Members of the mission were: D. McVey (Dept of Aircraft Production), Leader; D. E. Callinan (Beaufort Division engineer); AVM A. T. Cole (RAAF); Gp Capt W. S. Armstrong (RAAF); W Cdr J. P. Ryland (RAAF); and L. J. Wackett (Manager, CAC).

[7] An aircraft has only a limited range of possibilities for modification; there comes a time when it can no longer be modified and improved. The Spitfire, which had reached Mark VIII, was nearing the end of its development. The Mustang, on the other hand, was at the beginning and therefore a better choice because of its potentially longer future.

Of the American four-engined aircraft examined, the type that came nearest to fulfilling Australian requirements was the Liberator or B-24. Better still, however, was the Avro Lancaster bomber developed by A. V. Roe and Company in England, regarded by some authorities as the best four-engined heavy bomber produced in either Britain or the United States. At that time it carried the heaviest bomb load of all Allied aircraft.

While the mission was examining the question of the suitability of this aircraft, the Australian War Cabinet, in pursuance of the arrangement that had been made between the Prime Minister and the Commander-in-Chief of the South-West Pacific Area (General MacArthur) that the nature of the Commonwealth's war effort would be governed primarily by the Commander-in-Chief's plans, submitted for the latter's comment the proposal that Australia should make long-range bombers. In his reply to the Prime Minister (in March 1943) MacArthur adduced reasons for doing nothing of the kind:

> All of the larger types, including transport airplanes, can be flown from the United States and thus require none of the limited shipping space for delivery. Fighter airplanes must be brought in by surface ships, with considerable expenditure of cargo capacity. It is evident therefore that local manufacture of fighter aircraft would not only provide us with airplanes required in this category but would at the same time release worth while cargo ship space which could be used for other requirements. I believe therefore that insofar as the war effort is concerned, the local manufacture of fighter type airplanes would be preferable to attempting the manufacture of a type which can be flown to this theatre.

This definitely ruled out the Liberator, since Australia could hardly expect Lend-Lease support in these circumstances. Commenting later on the specific proposal to make the Lancaster in Australia,[8] MacArthur was no less emphatic: "There has been no new development which would tend to alter my opinion," he said. On the other hand the R.A.A.F. staff were not so easily convinced. It was their view that as a Service the R.A.A.F. was unbalanced, lacking particularly long-range general reconnaissance and heavy bomber aircraft which could be expected to give it a great deal more striking power than it possessed. Moreover, though it lacked aircraft of this type, it did have available large numbers of trained aircrews who had gained a great deal of experience in handling heavy, long-range aircraft in Europe.

Despite the lack of support from MacArthur, the Department of Aircraft Production recommended that the manufacture of the Lancaster should be undertaken. In addition to the arguments advanced by the R.A.A.F., there was the problem of maintaining continuity in the program of the government aircraft factories—the need to have some project to follow the Beaufort and Beaufighter. In the light of these considerations the War Cabinet finally approved of the setting up of facilities for the production of the latest type of Lancaster at a rate of 15 aircraft a month,

[8] The manufacture of the Lancaster had been first recommended by Storey in July 1941 after his visit to Britain with the Prime Minister, on the advice of the leading British authorities. The Lancaster was only then going into quantity production in England, as a replacement of the Manchester Bomber.

to a total of 50. By the time Australia was in a position to build the Lancaster, so many modifications had been made by its designers in England that it was virtually another aircraft and was in consequence renamed the Lincoln.

Manufacture of the Lincoln was a much bigger undertaking than any before attempted. The Lincoln dwarfed all aircraft previously made in Australia, as the following details will show:

Wing span	120 ft
Length	78 ft 4 in
Height	17 ft 3½ in
All-up weight	82,000 lb
Wing area	1,421 sq ft
Engines	4 Rolls Royce Merlin 85 1,660-h.p., 12-cylinder, ice-type liquid cooled in-line engines. Supplied at first from Britain, Merlin engines were later made in Australia.
Max speed	314 mph at 18,000 ft
Load	A bomb load of 22,000 lb could be carried

Headed by Storey, a team of Beaufort technical executives spent many months at the Avro works in Manchester in 1944 and 1945, and received the greatest help from the A. V. Roe Company.

The first Australian Lincoln was delivered to the R.A.A.F. on 10th May 1946; six others were completed before the year was out. The significance of this achievement lies not only in the size of the aircraft itself but also in the fact that for the first time Australia was able to build an aircraft at the same time as it was being developed in Britain. In the years immediately after the war it was not possible to repeat efforts of this kind. One of the main problems that confronted the industry in Australia then was to avoid manufacturing aircraft that became obsolete during the process.

The establishment of an aircraft industry in Australia would have been difficult enough under normal peacetime conditions. Under the adverse conditions of war, when demands were far in excess of supply not only for manpower and materials but for equipment of all kinds, the difficulties were infinitely greater. Nevertheless the aircraft industry became one of Australia's major undertakings, employing at the height of its activity (in June 1944) some 44,000 men and women. Women did a magnificent job for the industry: they worked lathes and milling machines, presses and drills; they worked as electric welders, riveters, assemblers, laboratory assistants, inspectors and tracers. In some Beaufort plants, for instance, as many as 57 per cent of the workers were women; over the whole organisation they made up about one-third of the total number of employees. More than 80 per cent of the men and women working in the Beaufort organisation had had no previous factory experience; less than 10 per cent of factory employees were skilled men.[9] One factor responsible for much

[9] These figures are taken from "The Organisation behind Torpedo Bomber Manufacture in Australia", an address delivered to the Institute of Industrial Management by its President, Mr John Storey, on 4 May 1943.

of the success achieved in producing aircraft and other munitions whose manufacture had not previously been attempted here, was the adaptability of Australian workers.

To have produced 3,500 aircraft of nine different types and nearly 3,000 aircraft engines of three types, must notwithstanding the mistakes and miscalculations that occurred, be ranked among the great achievements of Australian industry, especially when it is remembered that the fighter aircraft was one of the most highly complicated examples of precision engineering.

A fairly complete and well-balanced industry had been built up with parallel development of research, with the result that after the war Australia was capable of building aircraft and aero-engines of the most advanced jet-propelled types, such as the Avon-Sabre fighter, the Canberra bomber and the Rolls-Royce Nene engine, thereby establishing herself firmly as a strong link in the chain of air bases protecting the British Commonwealth.

CHAPTER 19

RADAR

ON 24th February 1939 the Prime Minister, Mr Lyons, received the following cable from the Australian High Commissioner in London: "Conversations have been carried on from time to time with the Air Ministry on the subject of secret research. They culminated today in the disclosure to the High Commissioners of a new development in defence applicable particularly to air but also probably capable of development for other services. The High Commissioners have been informed that if their Governments send their best qualified physicist to England all information will be placed at his disposal for secret report to Dominion Governments. Utmost secrecy is essential and the choice of a man of the greatest discretion important. I am satisfied that the new development which is the product of the best scientific brains here is of great significance and that the Commonwealth of Australia should be fully advised in relation to it. If you decide to send a man the idea is to attach to him either air or military liaison officer or both in order to obtain knowledge of service operation as well as scientific application of the new development. Utmost secrecy is imposed hence the absence of fuller information here. Air Ministry attaches such importance to it that they ask that details be not communicated by letter. Other High Commissioners are communicating similarly to their Governments."

The Prime Minister sought the advice of the Council for Scientific and Industrial Research, and on the recommendation of its chairman, Sir David Rivett, he chose Dr Martyn,[1] an outstanding physicist and officer of the Radio Research Board, for this important mission. To appreciate what lay behind the High Commissioner's cable and to gain some idea of the nature of the discovery that had been engaging the attention of the British Air Ministry for about five years, it is necessary to glance briefly at some of the early history of radio-communication.

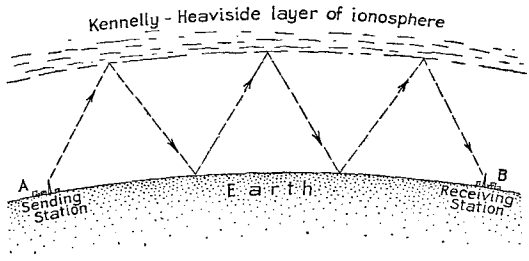
When in 1902 Marconi astonished his fellow men by transmitting radio signals 2,000 miles across the Atlantic Ocean, he also greatly puzzled scientists for it was known at the time that radio waves, like light waves, travelled in straight lines through homogeneous matter. What made radio waves follow the curvature of the earth rather than shoot off into outer space was the puzzling question. It was not long before an answer to this problem was given independently by Heaviside in England and by Kennelly in the United States, both of whom suggested that radio waves were reflected by an electrically-charged (ionised) layer of the upper atmosphere[2] acting like a mirror so that the waves reached a distant station

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[1] D. F. Martyn, FRS, DSc, PhD. Chief, CSIR Radiophysics Laboratory, 1939-42; Director, Army Operational Research Group, 1942-44; Chief Scientific Officer, Radio Research Board, since 1945. B. Cambuslang, Scotland, 27 Jun 1906.

[2] Later this layer came to be known as the ionosphere.

by a series of reflections from earth and sky, as shown in the accompanying diagram. That this was indeed the correct explanation was demonstrated experimentally by Appleton in England and by Breit and Tuve in the United States, who, in each instance, used the known speed of radio waves to calculate the height of the reflecting layer above the earth's surface. This distance was estimated to be about 60 miles (100 kilometres). Owing mainly to its intimate bearing on problems of long-distance radio-communication, but also because of its purely scientific interest, the nature of the ionised reflecting layer began to be intensively studied all over the world. It was while engaged on some experiments of this kind in December 1931 that several British Post Office engineers noted, more or less by accident, that radio waves were also reflected by an aircraft in flight several miles away. This observation was in due course published,[3] and in the following year was confirmed by engineers of the Bell Telephone Laboratories in the United States.[4]



British defence authorities, faced with the threat of another European war, were deeply concerned about the difficulties of defending the country from great fleets of bombing aircraft. Attacks might be made anywhere on Britain and it would be impossible to fend them off without a vastly greater force of fighters than the Royal Air Force was likely to possess in the foreseeable future.

Perhaps no one was more convinced of the overwhelming importance of air defence than Sir Henry Tizard,[5] a scientist who had served with distinction in the R.A.F. during the war of 1914-18. Tizard called together a committee of physicists to discuss the question of Britain's air defence, and out of their deliberations came a statement of what they regarded as the basic problem: how to obtain adequate warning of the approach of hostile aircraft.

The problem was put to the Director of Communications Development at the Air Ministry, Mr (later Sir) Robert Watson-Watt, who, with the earlier observations of the Post Office Engineers in mind, suggested that it could be solved by the use of radio waves. To test this proposal he immediately set about devising equipment for the study of the reflection of radio waves by aircraft, a task for which he was well prepared since he

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[3] F. E. Nancarrow, A. H. Mumford, F. C. Carter and H. T. Mitchell, *Post Office Radio Report* No. 23, Pt V, 3 Jun 1932.

[4] C. R. Englund, A. B. Crawford and W. W. Mumford, *Proceedings of Institute of Radio Engineers*, Vol. 21 (1933), p. 475.

[5] Sir Henry Tizard, GCB, AFC; FRS. (RGA and RAF in first world war.) Rector, Imperial College of Science, 1929-42; President, Magdalen College, Oxford, 1942-46; Chairman, Aeronautical Research Committee, 1933-43; Member of Council, Ministry of Aircraft Production. B. 23 Aug 1885.

had for some years been studying the reflection of radio waves from the ionosphere. It was well known that radio waves would penetrate darkness, cloud and fog,[6] but the problem of detecting an object as small as an aircraft at a distance of 100 miles was a formidable one. At that distance an aircraft would intercept only a tiny fraction of the radiation sent out from the transmitting station and this fraction would be correspondingly diminished when, after reflection, it reached a receiving set adjacent to the transmitter. A rough calculation showed that to achieve detection at this distance a radio receiving set would have to be capable of detecting about one million million millionth of the energy originally sent out by the transmitting set. Transmitters available in 1935 were capable of an output of 10^4 watts; receivers were sensitive to between 10^{-12} and 10^{-13} watts. These figures had to be raised to somewhere in the vicinity of 10^5 and 10^{-14} respectively if there was to be any hope of success. It is a tribute to the pioneers in this field of radio investigation that they persisted in the face of such unfavourable odds.[7]

The concept of radar, born of research into the nature of the ionosphere, appears to have occurred simultaneously and independently in Britain, the United States and Germany, but because of its important military implications it was developed under a heavy veil of secrecy. That each country should have arrived at much the same solution to the problems of military use of radio waves is interesting testimony to the inevitability of scientific discovery once the time is ripe for it, and to the futility of trying to keep fundamental discoveries secret for long. The need to develop a weapon of this kind was most acutely felt in Britain, and that is probably the main reason why it reached its greatest heights there quite early in the war.

In June 1935 Watson-Watt, working with a small team of collaborators,[8] observed radar[9] echoes from an aircraft in flight at a distance of 17 miles. This range was achieved essentially by concentrating the radiation sent out in short bursts or pulses of high energy. Further experiments by Watson-Watt and his team rapidly improved on this performance until an aircraft could be detected 100 miles away, and its distance and position could be measured. The distance, or range, was found by measuring the time it took radio waves to travel from the transmitter and back again to the adjacent receiver. The technique used for measuring the exceedingly small period of time involved was similar to that used for measuring the height of the ionospheric reflecting layer.[1] The time required for radiation transmitted in the form of rapidly repeated powerful pulses lasting only

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[6] The shortest radio waves (shorter than those generally used in radar) do not readily penetrate all types of cloud.

[7] E. G. Bowen, "The Uses of Radar in War". Univ of Sydney Engineering Club Annual War Memorial Lecture, 1946.

[8] This team included Dr E. G. Bowen, who later became Chief of the Radiophysics Laboratory.

[9] This method of locating objects was at first called radio location, or radio direction finding (R.D.F.). The term radar was introduced much later by the Americans. Although the term R.D.F. occurs frequently in the earlier accounts of work done in Australia, to avoid confusion the term radar will be used throughout the chapter.

[1] The method is discussed in Chapter 21.

a few millionths of a second to travel to and from the reflecting aircraft, was registered on the fluorescent screen of the cathode ray oscilloscope.[2] The distance of the vertical trace, or "blip", produced by the reflected radio waves from a zero point 0, was a measure of the distance of the aircraft. The scale was calibrated in miles or thousands of yards.

Aircraft were of course not the only objects capable of reflecting radio waves; ships at sea, and in fact all electrically conducting bodies, possessed this property to varying degrees. The method used by the early "chain" stations in England to obtain the bearing of a reflecting aircraft, for example, was to set two fixed receiving aerials at right angles to one another; its angle of elevation was determined by means of two identical aerials placed one above the other.[3] In order to attain the maximum range for detection of bombers flying at a medium height, transmitting and receiving aerials of the early-warning radar stations that ringed England on the outbreak of war were mounted on very tall lattice towers. From a military point of view it was unfortunate that the towers had to be so conspicuous, but strangely enough the Germans did not single them out for attack. From these towers radio waves were transmitted more or less equally in space, thus "floodlighting" the surrounding region. Standing on guard continually, day and night, this chain of radar stations was a decisive factor in winning one of the great battles of the war, the Battle of Britain.

This, then, in barest outline, was the remarkable and highly secret defence project into the techniques of which Martyn was to be initiated. In company with representatives from other Dominions he visited research establishments of the fighting services and also many of the coastal defence stations to study the system in operation during manoeuvres and the general problems of its tactical employment. He also took part in preliminary discussions on the role Australia was likely to play in radar: whether it would be the passive one of receiving equipment from Britain and merely distributing it or copying it; or whether it would be the more active and positive role of undertaking a program of research designed to fit in with the British efforts. Numerous developments in radar, adapting it to different kinds of military operational requirement, were to take place in the war years, and the decision ultimately arrived at, that Australia should undertake research and development as well as manufacture, was a most fortunate one. Conditions for military operations in the South-West Pacific Area were to prove so different from those in Europe that equipment well adapted for the latter was quite unsuitable in the Pacific theatre.

An important factor influencing the decision to make Australia a radar research centre was the circumstance that Australian physicists had for

[2] Radar technicians and others often referred to this as the radar "scope". It later became familiar as the screen of the television receiver.

[3] It is quite impracticable to describe these techniques in detail here. The reason for introducing any technical detail is to enable a description to be given of what radar did and its operational significance.

many years taken an active part in the study of the ionosphere, atmospherics and radio-propagation in general. Interest had first been inspired by Professor Madsen in Sydney and Professor Laby in Melbourne, who in 1924 had, with the help of funds provided by private broadcasting companies (2FC and 3LO), arranged for the establishment of fellowships to enable promising students in physics to undertake research. Sydney was to be the centre for the study of the ionosphere, and Melbourne for the study of atmospherics. This was only a beginning. The C.S.I.R., having obtained the promise of cooperation from the universities, the P.M.G. Department and the Services, set up the Radio Research Board under Madsen's chairmanship, with the object of greatly extending the field of radio investigations. For many years to come Madsen was to play a leading part in the encouragement of radio research in Australia.

From the very beginning of its activities the board planned its program of basic scientific research on the assumption that sooner or later the information thus gained would have important practical applications. In its planning it was fortunate in having the wholehearted and enlightened support of Mr Brown,[4] Director of Posts and Telegraphs. As a civil servant in charge of a public utility concerned, among many other things, with radio communication, he might have limited his support to projects assured of practical usefulness; instead, he encouraged to the fullest extent studies directed to a fundamental understanding of the ionosphere and the propagation of radio waves. This policy did eventually yield results of the greatest practical importance in radio communication, but its more immediate consequence was that it brought together a team of highly-trained scientists with a well-established reputation for research on the ionosphere to whom the techniques of radar could be readily and effectively communicated. Australia was therefore peculiarly well fitted to act not only as a subsidiary centre of radar research but as the leading one in the British Commonwealth should disaster have overtaken Britain itself.

Having sent on ahead a detailed report on the subject of radar to the Prime Minister, Martyn set sail from England on 22nd June 1939 armed with voluminous reports and blueprints and a number of important radio valves.[5] Soon after his return to Australia he was called to a conference with Sir David Rivett, Professor Madsen and Sir Harry Brown. On the basis of the information provided by the British Government the conference drew up comprehensive research and development plans for the benefit of the Australian Services. These included a recommendation to the Commonwealth Government for the establishment by the C.S.I.R. of a Radiophysics[6] Laboratory, the policy of which was to be the responsibility of an advisory board consisting of representatives of the three principal interests: scientific research, development and production, and the

[4] Sir Harry Brown, CMG, MBE. Director-General of Posts and Telegraphs 1923-39. C'wealth Coordinator-General of Works 1940-45; Chairman, British General Electric Co Pty Ltd, Sydney, 1939-53. B. Hylton, England, 28 Dec 1878.

[5] A number of complete equipments were sent to Australia separately.

[6] This name was invented to draw as little attention as possible to the laboratory's real purpose.

user.[7] After this scheme had been laid before the Chiefs of Staff of the three Services and had been approved by them, it was sent forward to the Federal Cabinet. At an informal meeting in Canberra, Rivett, Madsen and Martyn had no difficulty in persuading the Cabinet of the importance of radar for the defence of Australia and in obtaining a prompt acceptance of the scheme as it stood, together with an authorisation to spend approximately £80,000 on buildings, workshops and equipment. Owing to the need for secrecy no record was ever kept of the proceedings of this meeting.

The Radiophysics Advisory Board held its first meeting on 29th November 1939 and at this meeting authorised work on the first defence projects.

In order to provide a building for the work, it was decided to extend the National Standards Laboratory, the first portion of which had just been completed. This plan had the advantage of making the installation of a laboratory for secret work a little less conspicuous than it might otherwise have been. Its construction was pushed ahead with great speed and by the end of March 1940, thirteen weeks after the foundations had been laid, the building was sufficiently near completion for the staff to begin moving in.

The staff had not been idle in the meantime; facilities for the earliest work had been provided by the Electrical Engineering Department in the University of Sydney. The nucleus of a staff had been rapidly recruited from officers of the Radio Research Board and from a number of physicists who had been trained during their earlier association with the board but who had gone into the radio industry, the Commonwealth Solar Observatory or other establishments.

The relatively advanced state of television broadcasting in England just before the war had exercised an important influence on the development of radar since many of the techniques were readily adaptable. Among the recruits to the laboratory's staff was Dr Pawsey,[8] who had for a number of years been employed by Electrical and Musical Industries Ltd, the firm that was chiefly responsible for the development of television in Great Britain. The rest of the staff was made up of men who had recently graduated from university departments of physics and electrical engineering.[9] The staff was essentially one of young men, since the science of radio itself was young and younger men were mainly responsible for its develop-

[7] Members of the board at its first meeting were: Chief Executive Officer of CSIR (Sir David Rivett); Chairman of Radio Research Board (Prof Madsen); Director of Posts and Telegraphs (Sir Harry Brown); the three Chiefs of Staff (Vice-Admiral Sir Ragnar Colvin, Lt-Gen E. K. Squires and AVM S. J. Goble); Mr G. A. Cook was secretary. There were many changes on the board. Sir Charles Burnett replaced AVM Goble when he became Chief of the Air Staff. Similarly Maj-Gen J. Northcott replaced Lt-Gen Squires. Prof F. W. G. White served as chairman in place of Prof Madsen from 21 May to 10 Dec 1941 during the latter's absence overseas and became Deputy Chairman on his return. The appointment of Sir Guy Royle as Chief of the Naval Staff involved another automatic change in membership. In July 1942, in view of the possible importance of Australian radar activities in helping the U.S. forces, Maj O. Quanrad attended the meeting of the board, and from that time onwards American representatives took part in the deliberations which were of interest to them.

[8] J. L. Pawsey, FRS, PhD, MSc. Research physicist, EMI Ltd, England, 1934-39; since 1939 research physicist Radiophysics Lab, deputy chief since 1951. Of London; b. Ararat, Vic, 14 May 1908.

[9] In the first year of its operation the Radiophysics Laboratory had a staff of 5 research officers and 8 assistant research officers, with Dr Martyn as Chief of the Division.

ment, both in Australia and overseas. The training in fundamental physical research in communication engineering and electronics provided by Australian universities in the pre-war years, especially at Sydney, proved an excellent preparation for the men needed for this wartime activity. Indeed it is doubtful whether the extensive work which Australia undertook in radar would have been possible had research in allied fields of pure science not been fostered in the earlier years.

On the outbreak of war, and with the consequent dislocation of supplies, the Radiophysics Advisory Board decided that a representative should be sent to Great Britain to discuss future Australian developments and cooperation between the two countries, and also to arrange for the supply of complete units and essential parts. Madsen therefore made a hurried visit to England in December 1939. In discussions with Tizard, Watson-Watt and others he was able to have clarified the functions of the Radiophysics Laboratory. A memorandum was drawn up setting out its role in some detail. To make the best use of the limited number of appropriately qualified physicists in Britain and Australia, and to avoid serious overlapping of work, its research program was to be mapped out in consultation with leaders at the chief centre in Britain: the Telecommunications Research Establishment.

The principles to be followed in this collaborative effort were set out in a document which was presented to the Assistant Chief of the Air Staff, Air Marshal Sir Philip Joubert de la Ferté and communicated to the Secretary of State for Air, Sir Kingsley Wood. The document formed the basis for recommendations from the Air Ministry to the Governments of Australia and New Zealand. The Radiophysics Laboratory was also to obtain and hold reserves of essential parts, technical information and manufacturing designs; to act as a distributing centre for information and as a liaison office. Should the need arise it was to serve as the nucleus of an effective centre of production for the Eastern Group.

While in England Madsen laid the foundations for continuing close liaison between British and Australian scientific authorities in radar research by setting up the Australian Scientific Research Liaison Office in London with Mr Munro[1] as officer in charge.[2] Munro's duty was to keep Australia informed of the latest radar developments in Britain, to buy equipment, and to distribute reports of Australian work wherever they were required. On Madsen's initiative similar liaison centres were established in 1941 in Ottawa and in Washington.

As the potentialities of radar came to be realised, British scientists began to develop it for other operational uses than the early warning of approaching aircraft. Equipment embodying some of these advances was sent to the Radiophysics Laboratory and provided a great deal of information that was of the utmost value in initiating work in Australia.

[1] G. H. Munro, DSc. Research officer Radio Research Board 1929-39; Scientific Liaison Officer London 1940, Washington 1941-45; Officer in charge Radio Research Board Sydney since 1947. B. Clevedon, NZ, 23 Feb 1901.

[2] Others who held this office were Dr H. C. Webster (May 1941 to Jun 1943), Mr F. G. Nicholls (Jun 1943 to Sep 1944) and Mr G. B. Gresford (from Sep 1944).

With the release of information by Britain, the establishment of adequate personal contacts between research centres in Britain and Australia, the provision by the Australian Government of adequate scientific facilities, and arrangements for close collaboration between the Services and the research organisations, a sound foundation was laid for the development and manufacture of radar equipment in Australia.

At the second meeting of the Radiophysics Advisory Board, held on 13th March 1940 soon after Madsen's return from England, the program planned with British authorities for work in Australia was submitted for consideration and was approved. The board sent forward a recommendation to the Government that the Services should send officers to the United Kingdom to learn the operational uses of radar.

Early in 1940 it seemed unlikely that Australia would be subjected to either aerial bombardment or invasion. What seemed more probable was an attack on coastal cities and defences by cruiser squadrons, submarines, or isolated surface raiders. It was therefore decided to investigate equipment for shore defence and gunlaying. Neither the navy nor the air force was greatly concerned about the local development of radar equipment at this juncture; each hoped that it would be able to obtain all the radar equipment it needed from the United Kingdom. The army, on the other hand, in the person of Colonel Whitelaw,[3] commanding the coast defences in Eastern Command, displayed great interest; it was more through his encouragement and his great keenness to have some substitute for optical range finders, then in short supply, than from purely tactical considerations that the first work undertaken by the laboratory was the construction of a coast-watching or Shore Defence (Sh. D.) set. At the army's request the laboratory also began experimenting with air-warning equipment.

The development of the Sh.D. equipment established a pattern for all future activities of this kind. By close collaboration with the Services, in this instance the army, the operational requirements of the equipment were ascertained and the laboratory set to work to find out how far these requirements could be met with the existing radar techniques. A prototype model was then built and tested to make sure that it met operational requirements. For security reasons the manufacture of the equipment was at first confined to the P.M.G's Department.

The operational requirements of shore defence and of early air warning equipments were quite different from one another. The object of an early air-warning set was to detect approaching aircraft at a distance of about 100 miles. Range and bearing accuracy were of secondary importance, so long as they were sufficient to enable an estimate of the speed and course of the approaching aircraft. A shore defence set, on the other hand, was designed to warn coastal defences of the approach of surface vessels at about 20 to 30 miles and to assist gunlaying by finding the ranges of the vessels as accurately as possible. The differences in these two operational requirements were such as to call for radically different design. One set

[3] Maj-Gen J. S. Whitelaw, CB, CBE. (Served 1st AIF.) MGRA, LHQ, 1942-45. Regular soldier; of Upper Beaconsfield, Vic; b. Hawthorn, Vic, 26 Aug 1894.

had to detect a small object at a great distance and altitude; the other a much larger object on the surface of the sea and at a smaller distance. The shape and volume of surrounding space in which a radar equipment could detect a given target depended very much on the design and power of the equipment. Two principal systems of locating a target were in use: in one a relatively narrow beam of radio waves was moved systematically in a scanning process in much the same way as a searchlight; in the other the radar waves had a much wider spread, illuminating all the space to be searched simultaneously after the manner of floodlighting. The British Chain Home stations employed the floodlighting system; all Australian radar equipment was based on the scanning beam technique because of its greater economy in power.[4]

Though it naturally contained features of British equipment, the Sh.D. set was new in its synthesis of these features. It embodied one specially important innovation in its aerial system. Sets with a similar function in England had their transmitting and receiving aerials on separate towers 120 feet high. Pawsey, with the assistance of Minnett,[5] invented a system whereby one tower and one aerial were used for both transmitting and receiving. This enabled a notable saving, since each tower cost about £50,000. The Shore Defence station at Dover Heights, New South Wales, was the first in the British Commonwealth to be equipped with this type of aerial system. The arrangement was adopted in England for naval equipment and later underwent considerable improvement at the Telecommunications Research Establishment. In its improved form it returned to Australia. Quite independently a similar aerial system was developed in the United States. With a subject developing as rapidly as radar was then, simultaneous discoveries were neither unusual nor surprising. There was so much interchange of personnel and ideas that it was sometimes difficult to be sure where a discovery did originate.

The Sh. D. set operated at 10 kilowatts on a wavelength of 1.5 metres (200 megacycles). The short duration of the pulses of radiation employed (one millionth of a second) made it possible not only to discriminate between two ships if they happened to be fairly close together, but also to fix the range of a ship to within about 25 yards up to a distance of about 40,000 yards (about 23 miles). Discrimination and accuracy were gained at a sacrifice of range of detection, which meant that if the set were employed to detect aircraft its range was restricted to about 30 miles, which was totally inadequate for air warning. Sh. D. was greatly superior to the optical rangefinder, both in its range of operation and accuracy, and in the fact that it could operate in darkness and fog. Its coverage was attained by oscillating or rotating its narrow fan-shaped beam so as to cover an arc of about 180 degrees. A prototype of the Sh. D. set built in the Radiophysics Laboratory was erected for test on the army

[4] The analogy between radar and floodlighting and searchlight scanning breaks down at one point: visible light falls in a continuous stream, whereas in radar the radiation is discontinuous, taking the form of a succession of powerful pulses of short duration.

[5] H. C. Minnett, BSc, BE. Research officer, Radiophysics Lab, since 1940. Of Sydney; b. Sydney, 12 Jun 1917.

testing ground at Dover Heights, and during its first trials in May 1940 it picked up a ship off Port Stephens, a distance of about 90 miles.[6]

In February 1941 an "all radar" shoot with 9.2-inch guns and Sh. D. equipment, perhaps the first of its kind in the world, was held at North Head, Sydney. No suitable ship being available, a small improvised wooden target, fitted with a transmitting set to give the equivalent of a radar echo from a ship, was towed out to sea. When the order to fire was given, blips caused by shells falling near the target appeared almost simultaneously, just where they should have appeared, on the radar scope. The demonstration, successful beyond all expectations, made such an impression on army officers from Malaya who happened to be present, that they began making representations to have similar equipment sent to their own theatre. In August 1941 Dr Piddington,[7] a senior officer of the Radiophysics Laboratory, visited Malaya, Burma and Hong Kong to select sites suitable for Sh. D. and G.L. (Gun-laying) equipment; he was followed by a second officer, Mr Alexander,[8] who arranged the engineering details. All this effort came too late, though there is no reason to believe that the installation of radar equipment would have either delayed the fall of Singapore or made any significant difference to the course of the disastrous Malayan campaign.

While these negotiations had been going on, the manufacture of Sh. D. sets was making good progress. By this time the P.M.G's Department had arranged for commercial industry to manufacture some component parts of the equipment. A first instalment of seventeen sets had been ordered from the P.M.G's Department and a careful survey of the mainland coast to find suitable sites for their installation had been made by Whitelaw and two members of the laboratory.[9]

The army was well satisfied with the Sh.D. equipment and the whole coastline seemed to be reasonably well covered except for one region. Among the places at which it was intended to install the Sh. D. equipment was Darwin, but although Darwin was an important naval refuelling base, it was some time before any headway was made in providing it with an air-warning station. There were arguments as to which Service should bear the expense of the installations, and when war broke out with Japan Darwin still had no radar defence worth the name.

The new phase of the war brought a rapid change in the tempo of work on radar. By now the laboratory had gained useful experience in the general techniques since several other projects had been under investigation. For instance, an Air to Surface Vessel (A.S.V.) set designed for installation in aircraft for the purpose of scanning the open sea for enemy

[6] This unusually great range was probably due to atmospheric refraction, which is discussed later in this chapter.

[7] J. H. Piddington, PhD, BE. Research officer, Radiophysics Lab, since 1940. Of Sydney; b. Wagga, NSW, 6 Nov 1910.

[8] T. B. Alexander, BSc, BE. Research officer, Radiophysics Lab, 1941-45. Of Sydney; b. Sydney, 27 May 1915.

[9] In all 37 Sh. D. sets were built, at a cost of approximately £290,000.

ships, had been attempted. The intention was to install it in Beaufort bombers, which were then being made in Australia. Four R.A.A.F. wireless operators were given a grounding in the maintenance and operation of the set—the first R.A.A.F. radar operators to be trained in Australia. After the A.S.V. set had been tested with their help it was abandoned because it was by then obsolete.

With these early successes and failures radiophysicists had served their apprenticeship, tested and amended their laboratory organisation, and learned much of the difficult arts of scientific team work and cooperation with the armed services. The laboratory was fortunate in having built up so rapidly a strong *esprit de corps* which was to stand it in good stead in the two anxious years to follow. The staff had grown considerably and now numbered forty physicists.

Radiophysics attained the full status of a Division of the C.S.I.R. with Professor White[1] as its Chief. In 1942 Martyn left to become leader of an Army Operational Research Group, and White, who was at the time Deputy Chairman of the Radiophysics Advisory Board, took over the duties of Chief of the Division. For the next four years White, whose high scientific attainments were matched by his administrative ability, guided the work of the laboratory with remarkable foresight. As the laboratory grew it became clear that there was need for a production engineer on the staff, preferably one from the radio industry. The Gramophone Company Ltd at Homebush, New South Wales, agreed to release its factory manager, Mr Briton,[2] to organise this side of the laboratory's activities, and he was appointed Deputy Chief of the Division from 1st June 1943 for the duration of the war. A second Deputy Chief was appointed in January 1944 when by an arrangement with the Air Ministry Dr E. G. Bowen[3] (who was at that time with the Tizard Mission in the United States) was seconded to the Radiophysics Laboratory for two years.[4]

Until 1942 no one outside the Radiophysics Advisory Board, some senior officers of the Services and the staffs of the Radiophysics and P.M.G. Laboratories, knew anything about radar. Effective collaboration with the three Services had yet to be built up and instructional work on a large scale had still to be undertaken. It was clear that there would soon be a demand for radar equipment quite beyond the powers of the P.M.G's Department to supply. The only solution to this problem lay in mobilising the resources of the radio industry, but events moved too rapidly for the research men to wait for the reorganisation of production. As the swiftly

[1] F. W. G. White, CBE; DSc, PhD. Prof of Physics, Canterbury Univ College, NZ, 1937-42; Chief, Division of Radiophysics, 1942-45; Chief Executive Officer, CSIRO, since 1949. B. Johnsonville, NZ, 26 May 1905.

[2] J. N. Briton, BSc, BE. Works Manager, Gramophone Company, 1938-43; Deputy Chief, Radiophysics Division 1943-45, Chief 1945-46; Technical Director Electrical and Musical Industries, 1946-55; Chief Engineer, Television Corporation Ltd, since 1955. B. Sydney, 25 Dec 1907.

[3] E. G. Bowen, OBE; MSc, PhD. Air Ministry Research Station, Bawdsey, Eng, 1936-40; British Air Commission, Washington, 1940-42; Deputy Chief, Division of Radiophysics, 1944-45, Chief since 1946. B. Swansea, Wales, 14 Jan 1911.

[4] At the end of that time Bowen severed his connection with the Air Ministry and was appointed Chief of the Division.

moving tide of Japanese invasion overwhelmed regions to the north of Australia, the work of the laboratory was intensified. Its great test was about to come.

The best defence against the bombing attacks likely to be launched by the Japanese was to ward them off by means of fighter aircraft. If approaching enemy aircraft could be detected at a distance of 100 miles, sufficient warning could be given to enable fighter aircraft to intercept the bomber force some distance from its target. Since, owing to their high speeds and correspondingly high consumption of fuel, fighters could not remain in the air for long, a great increase in the efficiency of their defensive use could be expected with adequate air warning. These tactics had been thoroughly tried out and proved in the Battle of Britain. In the face of imminent bombing attacks from the Japanese there was therefore an urgent need for an air-warning radar equipment.

Beginning on 7th December 1941 and working at top speed, a group of physicists under Piddington's leadership improvised an air-warning set from component parts then to hand: the modified receiver of an experimental A.S.V. set built earlier in the year, the aerial previously designed for the Sh.D. set, and none-too-powerful valves (type VT.90, later made in Australia) designed for airborne transmitters, where light weight was of first importance. The air warning set was in effect a radically-modified Sh.D. set. Its greater range, secured at the expense of accuracy and of the ability to discriminate between close targets, was obtained by decreasing the band-width of the receiver and at the same time lengthening the transmitted pulse from 1½ microseconds to 20 microseconds. What this amounted to was putting more energy into the bursts of outgoing radiation and making the receiving set more sensitive. Thus it was possible to avoid the need for increasing the power of the set, which owing to the nature of the valves then procurable in Australia was limited to about 10 kilowatts, a figure well below that of corresponding British equipment. After this neat piece of adaptation had been achieved, an adequate range for air warning purposes was obtained, but successful use of the equipment called for considerable skill on the part of the operator. The set used the same frequency as the Sh.D., namely 200 megacycles per second (corresponding to a wavelength of 1.5 metres).[5]

The set was so hastily put together that normal safety covers were omitted and high-tension wires were accessible and a constant danger to the maintenance crew. But although it lacked a neat factory finish, the set was efficient, as it proved within a week by detecting an aircraft about 65 miles off Dover Heights. For many months this was the only means of warning Sydney of the approach of enemy aircraft. Fortunately, though for some time Australia's fate hung in the balance, the bombers never came to Sydney.

Immediately after successful trials, the construction of six more A.W. sets was begun. These sets were built jointly by the Radiophysics Labora-

[5] This frequency band was later used for commercial television in Sydney.

tory and the Gramophone Company Ltd, where at this time Briton had charge of the factory. The laboratory had only a very small workshop, and it was imperative to have more space and assistance. The pressure of events was great and there was no time to waste, so with the concurrence of the Department of Munitions an arrangement was made with the Gramophone Company: some sets were made in the laboratory with men from the factory helping; others were made (by hand) in the factory with the help of men from the laboratory workshop. The first three sets, with a full supply of spare parts, completed by 4th February 1942, were made to a better general design and finish than the prototype. They were installed at Darwin, Port Moresby and Port Kembla; the next three were completed two months later.

The set sent to Darwin was accompanied by technicians of the R.A.A.F., who, though they were without manuals to guide them, felt confident of their ability to operate it. When an attempt was made they failed even to get the set on the air. While they were still trying to get it working the Japanese made their first raid on the town. Surprise was complete and defence so weak—the only serviceable aircraft round Darwin that day were 14 Wirraways, 17 Hudsons, and some American P-40s passing through on their way to Java—that great destruction was wrought by the enemy. Commenting on the failure of the Darwin defences in his report on the Commission of Inquiry, Mr Justice Lowe[6] wrote: "An installation of the type used in Great Britain was at all these times available but it was only on the last date (September 1941) that a decision was taken to erect another unit, which was described in evidence as a makeshift, at Darwin. But even then the question of implementing the decision was apparently treated with a leisureliness out of keeping with the urgency of the occasion."[7]

There were probably a number of reasons for the early failure of radar at Darwin. It is fair to say that it was not due to a lack of technical competence on the part of the radiophysicists, but rather to their inability to convince the Services of the potentialities of radar. To some extent delay in recognising the value of radar was inherent in the general situation at the time, but it was also due to the fact that the laboratory would rush prototype equipments into operational trials before they were really ready for use. Something would go wrong during the trial, and the physicist would put in a condenser here or a resistance there, when everything would be right again. Incidents of this kind tended to shake the confidence of the Service authorities present and to give them the impression that radar was a tricky device that only an expert could handle. Being an extremely closely-guarded secret, the possibilities of radar had not yet been made as extensively and thoroughly known to the Services as they might otherwise have been.

[6] Hon Sir Charles Lowe, KCMG. Justice of the Supreme Court of Vic, since 1927, Acting Chief Justice 1950 and 1953; Chancellor, Univ of Melbourne, 1941-54. B. Panmure, Vic, 4 Oct 1880.

[7] *Parliamentary Papers* No. 40 (1945).

There was, however, little time for a post-mortem on Darwin's disastrous bombing. Japanese raids continued to occur daily, and without effective opposition, for some time. An urgent call issued to the Radiophysics Laboratory brought Piddington, the group leader of the air-warning project, and an assistant, Mr Cooper,[8] post-haste to Darwin. After some tense days, not made any easier by rumours of an impending Japanese invasion,[9] the air-warning set was got going on 22nd March 1942. Five days earlier a squadron of American P-40s had arrived. The radar had not been long on the air when at 11.30 a.m. the screen showed an aircraft or group of aircraft 84 miles east of Darwin. This was immediately reported to Fighter Operations Room and subsequently a plot of the course was given. The speed was estimated at 160 miles an hour and the height between 12,000 and 14,000 feet. A few minutes later a second indication was obtained 62 miles from Darwin in the same direction. About 20 minutes after the first warning, Fighter Operations said that our aircraft had engaged the enemy, 20 miles from Darwin. A little later the radar station reported numerous indications of aircraft retreating in different directions and at different distances. One Japanese bomber was shot down.

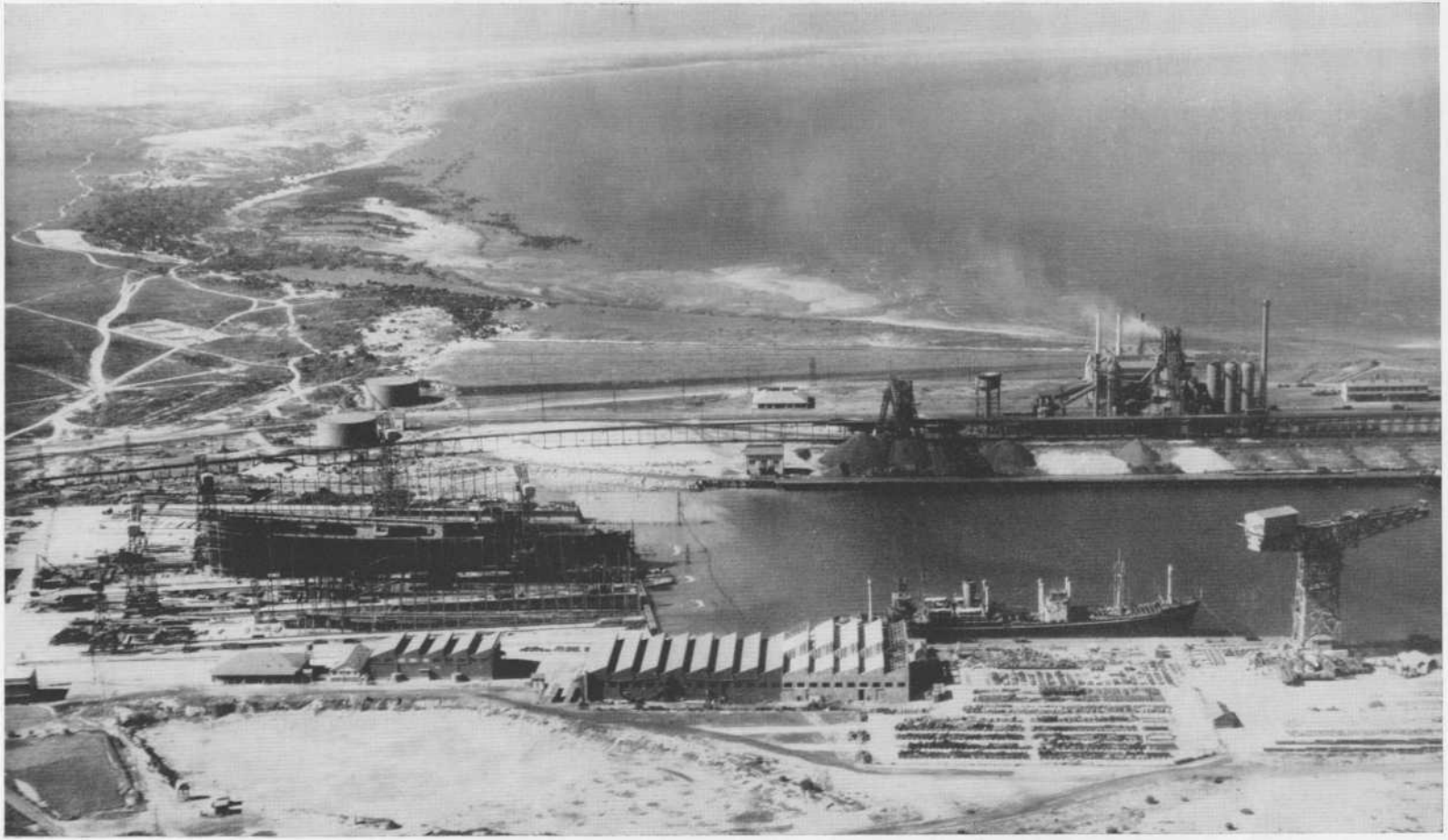
Radar was no longer a new-fangled invention to be regarded with suspicion, but a valuable weapon. Faith in its efficacy grew rapidly, sometimes to limits beyond its deserving. It was well known to the radiophysicists that the air warning set did not, because of the interference of radio waves reflected from the earth, cover regions near the ground. Had the Japanese known this, they could, by flying at a low level, have come quite close in to the target before their presence was detected. Fortunately for Britain, even the German pilots did not know of this trick early in the war.[1] The German pilots did learn it later, and long after the Darwin raids passed the trick on to the Japanese just as their air strength was nearly exhausted.

The only other mainland A.W. station to make contact with the enemy was one at Townsville. An American gun-laying set that had been intended for the Philippines was adapted for air warning by the staff of the Radiophysics Laboratory and sent north. An officer and a party of twelve men were charged with installing and looking after it. This was in the days of extreme secrecy, and the party experienced considerable difficulty with the local commander, who knew nothing about radar. Because members of the installation party were sworn to secrecy they were unable to give a sufficiently convincing explanation of their mission, but eventually they managed to set up the equipment and get it working. With it they observed the first Japanese raid on Townsville—a reconnaissance raid. No guns

[8] B. F. C. Cooper, BSc, BE. Research officer, Radiophysics Lab, since 1940. Of Austinmer, NSW; b. Eaglescliffe, Eng, 15 Oct 1917.

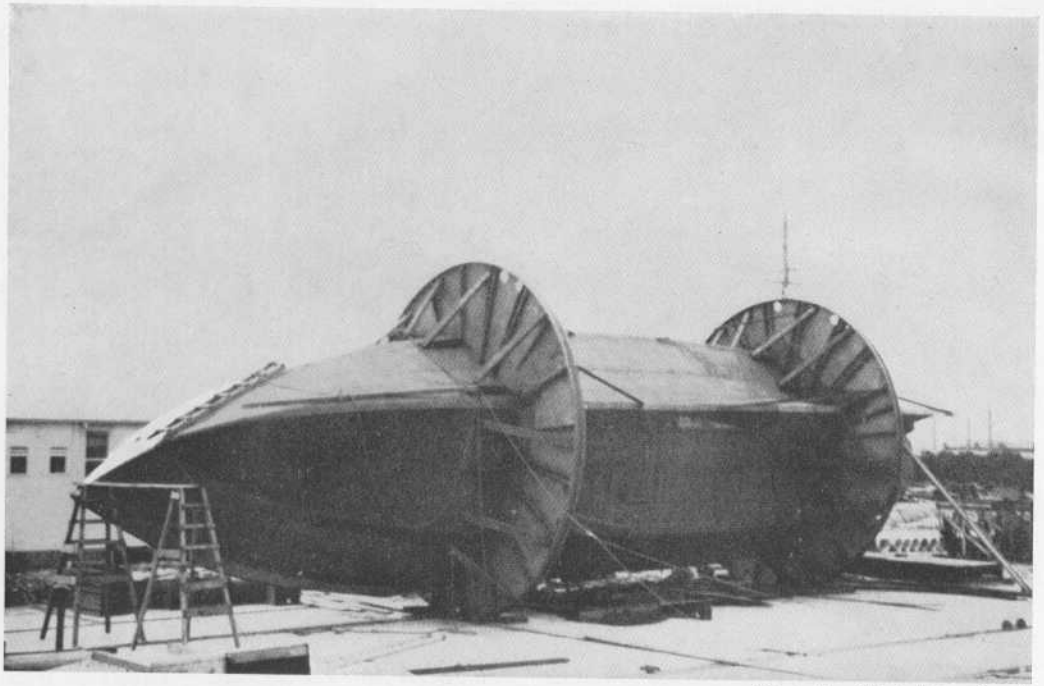
[9] The RAAF reconnaissance aircraft had noted the assembling of 28 Japanese transports at Koepang. Another disturbing observation that lent colour to these rumours was the fact that although they could have destroyed them with the greatest ease, the Japanese had left the oil installations at Darwin untouched by their bombing.

[1] It is almost certain that German scientists were aware of this possibility but it does not appear to have been known to those responsible for tactics. The most reasonable explanation would appear to be that liaison between the two groups was weak or non-existent.



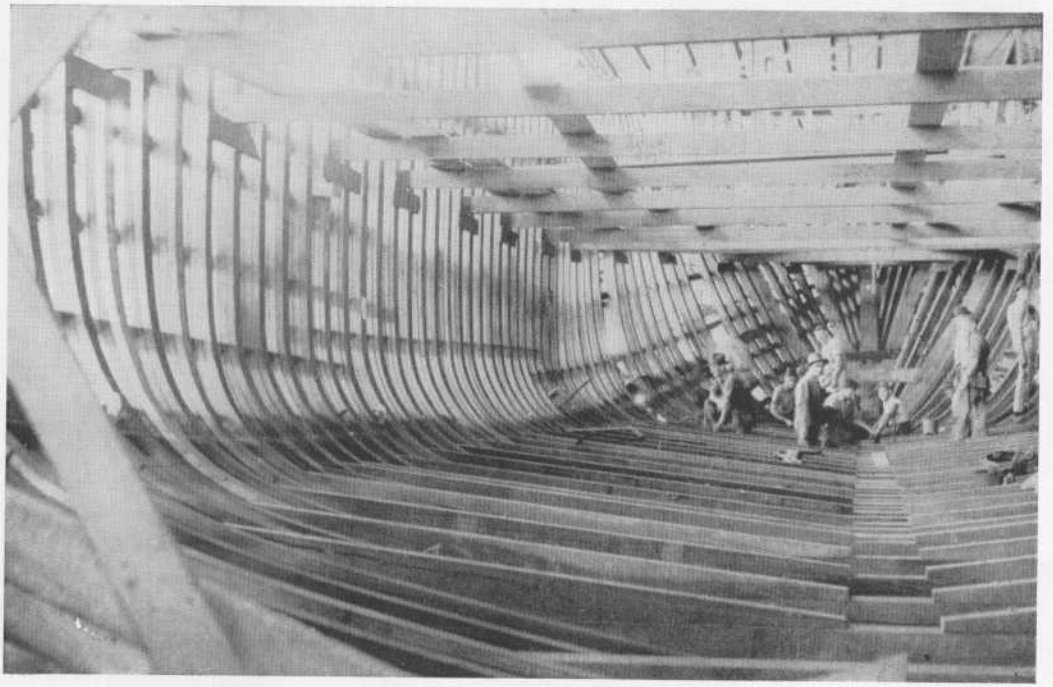
(*B.H.P.*)

Whyalla, South Australia: a busy industrial centre on a lonely stretch of coastline. In the foreground is the shipyard, and at the right is the blast furnace.



(*Australian Shipbuilding Board*)

Construction of 75-foot tug: roll-over jig for down-hand welding, designed by Mr H. P. Weymouth and by Mr E. F. Hewitt of J. and A. Brown and Abermain Seaham Collieries Ltd and made by Bernard Smith Pty Ltd.



(*Western Mail, Perth*)

Building wooden ships in Western Australia.

were fired, and no aircraft were sent up. In the second raid anti-aircraft guns went into action and the pilot jettisoned his bombs harmlessly out to sea. In the third raid two United States Army Air Force night fighters, whose movements were controlled by radar, successfully intercepted and brought down the bomber.

Many of the A.W. stations on the mainland and on adjacent islands were in extremely lonely spots, with climates ranging from the extreme cold of Wedge Island to the humid tropical climate of Hammond and Mornington Islands. A radar station consisted as a rule of about thirty-five men, including a medical officer, guards, cooks and a clerk or two as well as operators and a maintenance officer. Crews were cut off for long periods in an environment which was often anything but comfortable and where they might suffer tropical ulcers and persistent tineas. Stations had to be operated in shifts throughout twenty-four hours of the day, and even though it was recognised to be of vital importance the work of watching the radar scope in a stuffy cubicle day after day became extremely boring.

An unusually bad station as regards amenities "was the one at Mornington Island of the Wellesley Group in the Gulf of Carpentaria. It was—and presumably still is—a most desolate island, 65 miles long with an indeterminate coastline of mud melting into the sea, the highest point on the land being 80 feet above sea level. It was inaccessible, surrounded by treacherous seas where submerged 'nigger heads'[2] were calculated to rip the bottom out of unwary ships. Here the thirty-two men of the radar station were dumped with twelve months' stores which had to last fifteen months, and here they stayed without relief. Fishing was the one amusement. Bathing was impossible because the waters were infested with Portuguese men-of-war.[3] Mail was the most serious deprivation. At the end of fifteen months the station was withdrawn. In all that time the men had not been relieved."[4]

The Sh. D. sets, which with the help of Dr Myers reached a high degree of efficiency as aids to gun-laying, were never used against the enemy. It was one of the ironies of the history of radar development in Australia that the Service taking the greatest initial interest in it should have found the least operational use for it. This, of course, was no reflection on those responsible; when Sh.D. sets were built no one knew what course the war in the Pacific would take.

Even before the chain of A.W. stations had been completed the immediate threat to the mainland had passed. Having fulfilled a defensive role by means of a relatively small number of hastily-built sets based on an improvised model, radar was soon to be used in a more positive and thorough-going fashion by all three of the armed Services in the islands north of Australia. But before relating this we must return to the story

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[2] Nigger heads are boulders of coral which have been broken off by heavy seas and thrown haphazard upon the surface of the reef.

[3] A colonial jelly fish, one of the most beautiful of the pelagic group *Siphonophora*, found in tropical seas. Its sting is exceedingly powerful and may have serious results.

[4] Marjorie Barnard, "Radar", an unpublished account.

of the laboratory and industry to see how they were organised to meet the swiftly-growing demands of the Services.

While the first A.W. equipments were being built there was considerable discussion whether the Radiophysics Laboratory should continue to build prototype models. In peace time the development of equipment as complicated as radar would be spread out over many years: there would be time for the scientist to complete his work and then hand it over to the engineer to put into the form of a prototype equipment which would be thoroughly tested to see that it met the needs of the user before it went into quantity production. In war each step had to be taken much more rapidly—sometimes before a preceding one had been properly completed. Some way had to be found for accelerating the transition from prototype model to quantity production.

In January 1942, after discussions between Mr Brodribb, Deputy Director-General of Munitions, and the Radiophysics Advisory Board, the Department of Munitions brought into being the Directorate of Radio and Signal Supplies with Lieut-Colonel Jones,[5] a former engineer of the P.M.G's Department, as its Director.[6] Originally intended to deal with radar equipment alone, the directorate's functions were enlarged in July 1942 to cover all radio and signal supplies. In general terms, it was this directorate's responsibility to plan and organise production of radar and telecommunication equipment in commercial industry to meet the requirements of the Services. Its responsibility included opening up new productive capacity, promoting new techniques, selecting contractors, procuring oversea supplies, and encouraging and assisting production generally.

The volume of material relating to technical aspects of research, development and production grew so large that the Radiophysics Advisory Board was unable to deal with it at its monthly meetings. In order to provide a medium for the detailed discussion of the purely scientific and technical problems, the board set up a Technical Committee,[7] which met for the first time on 7th January 1942.

Early meetings of the Radiophysics Advisory Board took place in extreme secrecy. Unusual precautions were taken in the handling of all matters, and for this reason the Chiefs of Staff attended meetings of the board in person until 1942 when service requirements became so comprehensive that it was necessary for specialist officers to attend meetings.

In September 1942 Sir John Madsen resigned from the board and was succeeded by Mr McVey,[8] whose extensive administrative experience as

[5] Lt-Col S. O. Jones, PMG's Dept 1927-39; comd AIF Signals in UK 1940-41; Dir of Radio and Signal Supplies 1942-45; Technical Manager, Philips Electrical Industries of Aust Pty Ltd, since 1945. B. Frankston, Vic, 20 Aug 1905.

[6] Col Jones was director until 30 Apr 1945, when he was succeeded by Mr A. S. Ford. The controllers of the directorate were successively Messrs W. J. Richards, R. J. Bussell, D. S. Ash and F. Tracy.

[7] Members were: Prof F. W. G. White (Chairman); Cdr H. J. Buchanan and Lt T. S. Cree (RAN); Col C. C. Wright, Lt-Col F. N. Nurse and Capt M. R. Buring (Army); Gp Capt C. S. Wiggins and F Lt J. T. Phillips (RAAF); Messrs S. H. Witt and E. J. Stewart (PMG's Dept); Lt-Col S. O. Jones (Dept of Munitions); Mr G. A. Cook (CSIR), Secretary.

[8] Sir Daniel McVey, CMG. (Served 1st AIF.) Dir-General of Posts and Telegraphs 1939-46; Dir-General Civil Aviation 1944-46; Secretary, Dept of Aircraft Producn, 1942-45; Chairman, Radiophysics Advisory Board, 1942-46; Managing Dir, STC Pty Ltd, 1946-49. B. Falkirk, Scotland, 24 Nov 1892.

Secretary of the Department of Aircraft Production did much to assist the board in organising the production of radar equipment by commercial industry.

From the outset Australia had maintained a close liaison with Britain on the development of radar; the time had now come to strengthen liaison with the United States. The growing dependence (especially after the end of 1940) of Britain on Canada and the United States for the supply of radar components, and the greatly increased activity in the United States on radar, were among the reasons for Australia's drawing close to North America in this field. In the latter part of 1942 the staff of the Scientific Liaison Office in Washington was increased by the addition of two scientific officers.[9] Information was coming forward so freely that the main problem was to keep it down to an assimilable—and indeed a despatchable—quantity. Since the material was secret it went by diplomatic bag, and the weight allowed always seemed much less than the amount awaiting despatch. In the interests of efficiency it was necessary to sift the material carefully and send it in order of importance. The work could be done only by men with scientific training, and it consumed a great deal of their time.

The transfer of technical information during the war years through the Scientific Liaison Offices was much faster than in peace time. In normal times it is customary to publish the results of scientific investigations in journals, a process often entailing considerable delay. In war time the results were cyclostyled and were distributed far more rapidly. Information on paper alone was, of course, not sufficient to ensure the transfer of scientific techniques, which could often not be put into writing. Throughout the war, but beginning intensively in 1942, there was a constant interchange of scientists, particularly physicists, between Australia and Britain and the United States. Those who experienced them did not soon forget the valuable opportunities for discussion provided in this way. It would be difficult to assess in precise terms the influence of these interchanges on the development of science in Australia, but it was considerable.

Among the distinguished Americans who visited Australia was Dr Karl Compton, President of the Massachusetts Institute of Technology. He came to investigate the possibility of extending to Australia the activities of the Office of Field Service, a section of the Office of Scientific Research and Development, and of effecting a liaison between it and the Radiophysics Laboratory. His visit resulted in two important developments: the formation of the Research Section General Headquarters, and the sending out of a group of five physicists from the Radiation Laboratory at the Massachusetts Institute of Technology to collaborate with members of the Radio-

[9] The staff at this time comprised G. H. Munro, M. M. Lusby and V. D. Burgmann. The Radiation Laboratory of the Massachusetts Institute of Technology had become such an important centre at the beginning of 1943 that a scientific liaison office was set up there under Burgmann. The Australian contact with the United States was made essentially through the British Central Scientific Office (BCSO) in Washington. The duties of the body were similar to those of the ASRLO in London.

physics Laboratory on radar countermeasures.[1] In return the laboratory undertook work on the development of special equipment for the American forces. The Office of Scientific Research and Development maintained a most generous attitude to the release of secret information to Australia and helped from time to time by sending written information and by providing models of the latest types of equipment.

Similar contacts were made with Canada. The Acting Chairman of the National Research Council of Canada, Dean McKenzie, offered Australian liaison officers and visiting scientists full facilities for obtaining information about the Canadian program and Canadian research and development, especially that of Research Enterprises Ltd, a government organisation set up in Canada for the manufacture of radar and other wartime equipment. Dr W. R. McKinley, a Canadian authority on radar, visited Australia, spending much of his time at the Radiophysics Laboratory and the rest on an extensive tour of operational areas in New Guinea. From time to time Canada provided pieces of equipment urgently needed, either as part of the Australian research and development program or to fulfil the needs of the Australian Services.

Scientific liaison between Australia and Britain, the United States and Canada, established in the first instance to meet the needs for developing radar, gradually extended to many other branches of science, and continuing after the war promised to become a permanent feature in the scientific life of Australia.

During 1942 the problem of instructing members of the Services in handling and operating new and quite unfamiliar equipment, became a serious one and had to be tackled systematically. Not only was the equipment novel, but the continual introduction of modifications and improvements necessitated revision of instructions. For example, the first sets (Sh.D. and A.W.) used wavelengths of about 1.5 metres, but early in 1942 equipment operating on very much shorter wavelengths, in the region of 10 centimetres, and calling for different handling, was introduced. In setting up centres of instruction it was natural that the Services should turn to the Radiophysics Laboratory for help. The laboratory provided courses of instruction for men already partly familiar with the subject who were to become radar instructors at the Service training establishments.

It became clear that although the laboratory could do a certain amount of instructional work, which was of course within its terms of reference, much more would be required than it alone could give. After somewhat protracted negotiations, the help of the University of Sydney was enlisted. Courses were arranged and conducted by Professor Bailey[2] in the Department of Physics. Here men of all three Services who were to become

[1] This group was known as the Australian Group Radiation Laboratory, and was led by Dr S. Seely.

[2] V. A. Bailey, MA, DPh. (Served in RE in first world war.) Prof of Experimental Physics, Univ of Sydney, 1928-52, Research Prof since 1953. B. Alexandria, Egypt, 18 Dec 1895. He was assisted by Dr M. Fraser, Dr R. E. B. Makinson and Mr J. M. Somerville.

officers in charge of radar equipment and who had some preliminary knowledge of physics (up to second year B.Sc. standard) were given instruction in courses lasting six months, comprising lectures and extensive practical work.[3] In all about 300 men passed through this school.

The first notable technical development after the reorganisation in 1942 was the further improvement and adaptation of the air-warning equipment and its commercial manufacture on a relatively large scale. Experience with A.W. sets on the mainland and adjacent islands had shown that considerable difficulties arose when installing it in isolated and inaccessible spots. It was true that these installations were for fixed defences, and however difficult it was to set them up initially, once they were set up they were not usually moved again for some time. Conditions in New Guinea were extremely difficult, and the problem of transporting heavy and complex machinery through swamps and jungles in the absence of roads, railways, airfields, jetties and wharves demanded much thought and ingenuity. No matter how efficient a radar set was technically, it was useless if it was so cumbersome that it could not be got to the place where it was required. On the other hand, the situation was not much better if a set was made so light that, though it could be got to the place where it was required rapidly enough, it was liable to break down after a short time. For use in New Guinea and other tropical regions something between these two extremes was needed; something that could be transported by air and sea, and if necessary by hand through the jungle, without damage, and that could be assembled and put in operation within a few hours of its arrival at the site. Equipment evolved to meet these conditions, known as the Australian Light-weight Air Warning set (LW/AW Mark I), came as near as any made by the Allied countries to being ideal in respect of reliability and portability.

The A.W. sets used at Darwin and other places on the mainland were unusually light for this kind of equipment—not so much as a result of conscious planning to this end as by necessity. The only suitable valves available in Australia at the time the original A.W. set was designed were small and of relatively low power, and by using them it was possible to keep down the weight of the set. The great merit of the design was that it enabled the set to do the work of one equipped with high-powered valves. It was no discredit to the design that its light weight should have been more or less accidental. By deliberate planning still further improvements were effected. The set finally evolved which most nearly met the requirements of portability, weighed, when fully packed for transport, somewhere between 4,000 and 6,000 pounds.[4, 5]. If the weight exceeded the upper limit there was a serious loss of mobility and ease of erection.

[3] The standard was relaxed in later courses to admit men with no more physics than a pass at the school Leaving Certificate standard.

[4] This included power supply—a Ford "10" petrol engine alternator.

[5] J. N. Briton, "Light-weight Warning and G.C.I. Radar in Australia", *Journal of the Institution of Engineers, Australia*, Vol. 19, Jun 1947.

On the other hand, if the weight fell below the lower limit, it was very difficult to meet the full operational requirement for range and reliability.

The size of the aerial system was an important factor in determining the range of a set, and it could not be reduced below a definite minimum. Designing a suitable aerial was one of the greatest problems in keeping the weight of a set down. The problem was essentially one of mechanical engineering and was solved principally by the staff of the Chief Electrical Engineer's Branch (and the Mechanical Engineer's Branch) of the New South Wales Department of Railways.[6] In a discussion between representatives of the Air Force and the Railways it was decided that all components should be small enough to be placed inside a DC-2 aircraft. Saving of weight was effected chiefly by reducing that of the aerials and of the hut accommodating the set. The first step was to design an aerial with the whole of its rotating gear on the top of the hut. The aerial itself was made lighter and was so designed that it could be quickly dismantled into three sections. Previously more or less any kind of hut had been used to house the set; in the new equipment the hut was a pipe framework enclosed by a canvas tent.

These small engineering details helped to produce one of the most versatile and useful pieces of scientific equipment issued to the Services. Whereas the Australian LW/AW equipment weighed only 2 to 3 tons, corresponding American equipment sometimes weighed as much as 40 tons. The LW/AW Mark I set had good qualities apart from its portability. It was simple and rugged in construction, and because its component parts were readily accessible it was easily maintained. Australian radar crews received a much longer training than, for example, American crews, and were able to make practically all repairs in the field.

The first LW/AW Mark I set completed was set up at Dover Heights in September 1942.[7] Extensive tests demonstrated its ease of erection and dismantling. The radar equipment itself made up only 15 per cent of the weight of all the materials, including food for the crew, required to establish a radar station. An assessment of the set's performance by the Army Operational Research Group is shown in the accompanying table.

Although no great pains had been taken to tropic proof the first LW/AW Mark I equipments, once they were erected and put in operation in New Guinea they performed remarkably well. This was due partly to the highly efficient maintenance work of the R.A.A.F. technicians, and also to the fact that heat generated during operation of the equipment was sufficient to prevent the condensation of water that so often put electrical

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[6] Throughout much of the war the NSW Railways made a very valuable contribution to the radar project by designing and manufacturing aerials of all kinds. A special Radar Annexe was established in the Dept of the Chief Electrical Engineer (Mr W. H. Myers). Mr J. G. Q. Worledge and his team did outstanding work in this field.

[7] Details of the set were:
Frequency: 200 megacycles per second,
Peak power: 10-15 kilowatts,
Pulse recurrence frequency: 50 cycles,
Pulse duration: 20 microseconds,
Aerial array: 32-element (4 bay, 4 stack broadside),
Weight: Transmitter 6.5 cwt, receiver 6 cwt, array 2.5 tons (all crated ready for transport).

equipment out of operation in the tropics. Since equipments were required to be in almost continuous operation, their satisfactory performance was ensured by switching on electrical heaters for the short periods when the sets were switched off for maintenance. From experience with the first

Range of detection by LW/AW Mk I (in miles) against twin-engined aircraft—front aspect

Mean height of array above surrounding sea or land	Height of aircraft in feet						
	500	2,000	5,000	10,000	15,000	20,000	25,000
	miles	miles	miles	miles	miles	miles	miles
15 ft	10	20	30	45	55	62	65
45 ft	15	28	48	70	88		
150 ft	25	48	75				
300 ft	35	65	88				

model some tropic-proofing measures were incorporated in later models (LW/AW Mark IA). These latter sets performed so satisfactorily that at a much later date the R.A.A.F. was not prepared to introduce a new mark (III) that was not only lighter but had greater range and reliability, being operated with sixteen to twenty times the power used in the Mark IA; the changes in routine involved did not, in the R.A.A.F's opinion, warrant the change-over from one mark to another.

In all, some 150 LW/AW Mark I and IA sets were made for the Australian and American forces.

Except for the aerials, which were made by the New South Wales Railways, LW/AW equipment was built at the Gramophone Company Ltd at Homebush. That is not to say that this company made all the components —far from it. For example the valves (type VT.90) were made by Standard Telephones and Cables Pty Ltd (S.T.C.), whose experience with telephone repeater and high-power transmitting valves used by broadcasting stations proved valuable. At one period the local production of VT.90 valves fell almost to zero owing to the failure in supplies of raw materials. The threat was so serious that to insure against a possible breakdown in the manufacture of the LW/AW equipment, the Radiophysics Laboratory designed a second mark using a then more-readily-available valve. In the event, Mark II was not needed.

The LW/AW equipment was also adapted for use on ships. One of the main problems was to keep the size of the aerial down so that it could be safely installed at some high point (preferably the mast-head) without upsetting the ship's stability. An aerial as large and as light as practicable was chosen, any deficiency in the size of the aerial being made up by increasing the power of the set. A set known as Type A.79 with a power of 80 kilowatts and a range of about 63 miles was built for cruisers and destroyers; for smaller ships such as corvettes and minesweepers a set known as A.286.Q, with a power of 160 kilowatts and a range of 60 miles, was developed.

Once the main strategical approaches to the Australian mainland and the operational bases in New Guinea were covered by air-warning stations, the Japanese air force found it difficult to make any undetected approach to these areas. This cover enabled the Allied air forces to dispose their fighter squadrons to the best tactical advantage. In the absence of such cover more aircraft would have been required than could possibly have been provided at the time. As in the Battle of Britain, fighters were directed to the attack where they were required so that a relatively small fighter force was able to repel enemy attacks made on a wide front.

Radar scored no-less-important successes when the tide of battle turned from the defensive to the offensive. The first air-transportable A.W. station (LW/AW Mark IA) was installed at Tufi, a headland on the north coast of Papua, after being flown from Port Moresby. It could not be landed on the headland itself but had to be carried overland from Wanigela. This station, erected in six days, gave much valuable warning information. About the same time another station was installed at Dobodura, the site of an airfield near Buna. This station gave help in covering the Allied forces besieging Buna by warning them of aircraft coming from Lae. It was also able to pass its information by radio communication on to Port Moresby, 100 miles away over the Owen Stanley ranges.

The difficulties of manning and operating radar stations in the tropics were even greater than they were on the mainland and its neighbouring islands. At Dobodura, for instance, it was noticed that dense vegetation in the neighbourhood of the radar station had a detrimental effect on its reception. An earlier poor performance of radar noticed at Milne Bay was later attributed to the same effect of neighbouring vegetation. The remedy was to clear the surrounding area, which meant practically abandoning all attempts at camouflage. The motto of this and other similar stations became "coverage before cover". Another station installed at Cape Ward Hunt for the purpose of covering the advance on Salamaua experienced a heavy tropical downpour the night it landed. The equipment was protected from this deluge by nothing more than tarpaulins, but it survived in working trim. By this time it had become the rule that a radar station should cover every operation. Before the attack on Lae by the 7th and 9th Australian Divisions, the radar station at Buna was moved to Tsili Tsili, above the Markham Valley. Shifting this equipment and setting it up at its new point of operation was achieved in the remarkably short time of three days three hours.[8] The Tsili Tsili station covered the Nadzab parachute drop and advance. It is a great tribute to the soundness of the design and portability of the equipment that it performed so well in what must have been one of the most difficult regions in the world in which to operate. The incidents related are only a few of many which occurred, but they are typical.

No account of the wartime development of radar in Australia would be complete without some reference to the use of microwave radiation. In the

[8] The radar officer in charge was F-Lt K. N. Bishop.

early days of radar in Britain, equipment operated on wavelengths ranging between 1 and 50 metres. It was, however, realised that a number of advantages would accrue from the use of radiation of much shorter wavelength—down to a few centimetres. The difficulty barring the way to the use of shorter wavelengths was the absence of valves capable of generating such wavelengths at high power. Two British scientists, Dr J. T. Randal and Dr H. A. H. Boot, engaged on fundamental research in Professor M. L. Oliphant's[9] laboratory at the University of Birmingham, solved the problem by the invention of a revolutionary type of valve known as the resonant cavity magnetron. When this valve went into commercial production in August 1940 it gave British radar a lead over other countries. It was a narrow margin of technological superiority, but sufficient to give Britain a vital advantage over Germany in the Battle of the Atlantic. Among the advantages arising out of the use of the magnetron three were of special importance. By reason of the fact that the first lobe of radiation from a set equipped with magnetrons was close to the ground (the height of the first lobe was proportional to the wavelength of the radiation used) microwave radiation enabled the detection of distant aircraft flying at low altitudes. Shorter waves gave greater accuracy in fixing the bearing of distant objects and much clearer definition of images on the scope.[1] Above all, it enabled the detection of small objects such as submarine periscopes and small craft that could not be picked up on a long-wave set. The discovery of the resonant cavity magnetron was probably the most notable step taken in radar since its inception.

In 1940 the British Government decided to disclose to America all British radar information, including that on the latest microwave techniques. Accordingly Sir Henry Tizard, accompanied by representatives of the Services and by civilian technical advisers, among them Dr Bowen, an original member of Watson-Watt's pioneer radar team, sailed for the United States in September 1940. At a conference in Washington British and American radar data were laid on the table without reservation. In the United States the initiative for work on radar had been with the navy and not with the air force as in Britain. Nevertheless similarities between the developments in the two countries were remarkable. There were, however, two notable differences: the Americans had developed neither airborne sets nor microwave radiation. Thus the British had something very substantial to offer. The Bell Telephone Laboratories were given the contract to manufacture the magnetron for the United States. A less direct, but no less important result of the British Mission was the formation by the National Defence Research Committee of the Radiation Laboratory at the Massachusetts Institute of Technology, which became one of the world centres of research on microwaves. When the time arrived for the

[9] M. L. E. Oliphant, FRS, MA, PhD. Prof of Physics, Univ of Birmingham, 1937-50. Director, Research School Physical Sciences, Aust National Univ, since 1950. B. Adelaide, 8 Oct 1901.

[1] In its later development the presentation of radar information underwent a particularly useful refinement. Radar waves were used to form a crude monochrome image of some of the salient features of the region of space being explored. A ship or aircraft would show up as a small blob, and bays and other features would often be fairly clearly indicated. This system was known as the plan position indicator (P.P.I.).

transfer of microwave techniques to Australia, it was from the Radiation Laboratory that many of them were learned.

The first intimation received in Australia that important results were being obtained in Britain from the use of very short waves (10 centimetres), came through the Scientific Research Liaison Office in London. The question of their possible use in Australia was discussed by the Radiophysics Advisory Board at its eighth meeting on 17th December 1940. About six months later, when it became apparent that very short wavelengths were likely to assume considerable importance, Pawsey was sent to the Radiation Laboratory to study the new techniques.

Although the introduction of microwaves was an outstanding innovation, it did not mean that their use was bound to displace that of all other wavelengths. Each range of wavelengths (metre and centimetre) had its own peculiar advantages, depending upon the operational use for which it was intended.[2]

Microwaves proved most effective for the detection of submarines and other small craft. It was natural therefore that immediately on his return to Australia in October 1941 Pawsey and his group should begin work on a microwave equipment for the navy. An experimental model of a set known as A271L (A for Australian, L for laboratory model) embodying imported magnetron valves, pending the manufacture of these components locally, was first tried out at South Head, Sydney, in July 1942. Propagation conditions were unusually favourable and the set's performance exceeded all expectations: a 6,000-ton ship was picked up at a range of about 45 miles. After this test the Australian Navy needed no further convincing about the potentialities of microwave radar in sea warfare. Sea search equipment (A271L) was developed in two forms, one designed specially for the navy and the other for the army as a coastal defence set, but before the equipment could be put into quantity production it became necessary to arrange for the local manufacture of magnetron valves.

Valves used in domestic broadcast receiving sets resembled electric light bulbs in so far as they contained metal components sealed into an evacuated glass bulb. Many radar valves were of a fundamentally different design. The magnetron, for example, consisted of a metal body to which some glass parts were sealed. It was this feature of its construction that made the manufacture of the magnetron more difficult than the usual run of valves.

Using oversea valves as a guide, Dr Martin and Dr Burhop[3] in the Department of Natural Philosophy in the University of Melbourne, succeeded in making a laboratory model of a magnetron by 23rd May 1942. It is one thing to build a complex device such as a magnetron in the labora-

[2] To illustrate this point it is worth mentioning that naval vessels carried two equipments: air-warning (operating on 1.5 metres) and sea-search (operating on 10 centimetres). When the versatility of radar came to be fully realised capital ships carried as many as 30 different equipments, each fulfilling some special purpose.

[3] E. H. S. Burhop, PhD. Lecturer in Natural Philosophy, Univ Melb, 1935-42; Acting Officer-in-charge, CSIR Radio Research Lab, Melb, 1942-44; Senior Scientific Officer, British Supply Mission in U.S.A. on Atomic Energy Project, 1944-45. B. Hobart, 31 Jan 1911.
Martin and Burhop had previously been working on problems relating to optical munitions. During a visit to Australia Prof Oliphant persuaded Prof Laby to release them for work on radar.

tory, but quite another to build hundreds exactly alike by methods of mass production. After Martin and Burhop had completed their path-finding work the production engineers of the Amalgamated Wireless Valve Company Pty Ltd and of Standard Telephones and Cables Pty Ltd took over. They split up the process of manufacturing magnetrons into a large number of separate operations, most of which were of a relatively simple character. A few, such as the making of metal-to-glass seals and the final sealing of the metal chamber, called for considerable skill. A vacuum-tight copper-to-copper seal of a plate to a cylinder was achieved by compressing between them at a temperature of 530 degrees centigrade a ring of gold wire.

The problem of supplying the high-conductivity, oxygen-free copper which gave the most successful glass-to-metal seals but which was made only in America, was solved when Metal Manufactures developed a more simply produced manganese deoxidised copper specially for the purpose. Australian-made VT.90 valves used this metal. The VT.90 was the first valve in the world designed specifically for pulse operation in radar equipment and the first to use thoriated-tungsten filament in a high-voltage close-spaced valve.

Metal-to-glass sealing techniques using manganese deoxidised copper developed on the VT.90 were available when magnetrons came to the production stage, and all magnetrons made by S.T.C. were independent of oversea copper. Tellurium copper for the bodies was made also by Metal Manufactures.The high precision required for machining the resonant cavities and the sealing of the bodies by gold diffusion seals were the major mechanical problems encountered by industry. The magnetron was the first Australian-made valve in which oxide-coated cathodes were used to produce very high peak currents during anode voltage pulses of several thousand volts. Production of reliable cathodes for this class of operation presented a manufacturing problem of no mean order.

The local oscillator (or klystron) used in radar receivers operating on centimetre wavelengths was a valve of revolutionary design employing the principle of velocity modulation of a focused electron beam within the valve. This beam reacted with a resonant cavity which was an integral part of the valve and which could be tuned over a limited range of frequency. Most of the 10-centimetre radar equipment and a good deal of test equipment used these klystrons (the CV.35), which were produced in Australia by Standard Telephones and the Amalgamated Wireless Valve Company.

Australian Consolidated Industries furnished glasses possessing specified coefficients of expansion. Manufacture of the powerful, permanent, alnico magnets needed for the operation of a magnetron valve was satisfactorily carried through by Quality Castings (Sydney) and Rola Ltd (Melbourne): Quality Castings was among the first to develop the technique of powder metallurgy in Australia.

Having successfully copied an oversea magnetron, Martin and his team next developed an original design for a magnetron to generate 25-

centimetre radiation. This valve formed the essential element of a greatly improved air-warning set built towards the end of the war.

The greater part of the work at the University of Melbourne, especially late in the war, consisted of the development of pilot models of oversea valves using locally-available raw materials. The intention was to use these as an insurance against emergencies. Had the necessity arisen, they could have been fairly promptly produced on a large scale. As it happened, no major production of radar equipment was completely held up for want of valves.

Some sixty microwave radar equipments were made by A.W.A. for the navy; these, installed in corvettes and destroyers, performed well and reliably.

The Radiophysics Laboratory in Sydney and the P.M.G. Research Laboratories in Melbourne undertook between them the development of some twenty different radar projects. There was the Air to Surface Vessel (A.S.V.) equipment, essentially a straight copy of an English model, which was made on a large scale (1,126 sets, Marks I and II) for the R.A.A.F.[4] There were sets for searchlight control, fire control, ground-controlled interception (G.C.I.), among other radar systems.

Ground-controlled interception was evolved to meet the problem of intercepting night bombers. Such a system supplied to a fighter pilot continuous information of friendly and hostile aircraft both in plan and in height, their relative heights to within plus or minus 500 feet. Twenty-six units (LW/GCI Marks I and II) using 1.5-metre waves were made by the Gramophone Company Ltd and the New South Wales Government Railways for the Australian and American air forces.

One of the few original Australian contributions to the techniques of radar was fated to be stillborn. Ordinary radar equipment, such as LW/AW, could with the aid of a few calculations reveal the speed of approach or retreat of a target. It was generally recognised that a great advantage would be gained if it were possible to adapt radio to measure speeds of objects instantaneously. As far back as 1935 Martyn had worked out theoretically a method of applying Doppler's Principle[5] to radar waves for the purpose of studying movements of reflecting layers in the ionosphere.[6] Equipment working on this principle was built and put into successful operation in the grounds of the University of Sydney by Dr Pulley.[7]

[4] ASV equipment was made by Eclipse Radio Pty Ltd (subsidiary of Electronic Industries, Melbourne) and also by A. G. Healing Ltd of Melbourne.

[5] Astronomers applied this principle to light waves in the measurement of speeds of heavenly bodies.

[6] Martyn applied the principle to the case of a transmitter radiating strong pulses as well as a weak continuous carrier wave on the same radio frequency. "At the receiver a few hundred yards away," explained Martyn, "the pulses reflected from the ionosphere (and weakened after travelling vertically upwards and downwards for several hundred miles) met and combined with the now comparable continuous wave which had travelled only the few hundred yards between receiver and transmitter. A movement of only 100 yards in the ionospheric reflecting layer caused the pulse to vary in amplitude from a maximum to a minimum and back again. A steady movement in the layer therefore caused a continuous 'fluttering' of the echo pulse, the rate of flutter giving the rate of movement of the layer."

[7] O. O. Pulley, PhD, BSc. Senior Design Engineer A.W.A. Ltd; Principal Research Officer Radiophysics Lab; Officer-in-charge of Radar Section Directorate of Radio and Signal Supplies. Of Sydney; b. Wellington, NSW, 5 Sep 1906.

When Martyn took charge of the Radiophysics Laboratory he suggested to several members of the staff that they try to adapt the principle to radar, but the technical difficulties appeared to be too great in those early days. Later, as Director of the Army Operational Research Group, Martyn once again suggested the problem, this time to Messrs M. I. Iliffe and J. W. Hill,[8] who solved it in a very skilful fashion. The equipment they constructed was so efficient that the rolling of the pilot steamer *Captain Cook* in the swell of Sydney Heads could be watched on the oscillograph screen. In point of fact Martyn claimed that a movement of one foot could be detected in an object 50 miles away.

The project, which came to be known under the code name "Flutter", was of special interest to the navy because of its possible application to naval gunnery where quick determination of changes in speed by the enemy was of great importance. To the air force it represented a useful method for identifying aircraft by their speeds, and also for picking out moving aircraft among fixed permanent echoes. Flutter reached the developmental stage about the same time as LW/AW, and much effort would have been required to take it further. The Radiophysics Advisory Board felt that the two projects could not be fully developed simultaneously, and decided, rightly as events were to prove, to go ahead with the LW/AW equipment.

Full information concerning Flutter was sent to the Admiralty, the Telecommunications Research Establishment and to the principal radar centres in the United States. The most important application of Flutter in use before the end of the war appears to have been in bombers, to enable rapid determination of their speed relative to their target. Flutter was described by the Director of the English Army Operational Research Group, in one of the regular information bulletins to sections abroad, as "the only instance which has arisen during the war of the application to radar of a radically different fundamental physical principle".

The Japanese did not take long to find a way of jamming equipment operating on the 1.5-metre wavelength. The Radiophysics Laboratory's reply to this was to develop equipment operating in the centimetre region. Towards the end of the war it evolved a highly satisfactory 25-centimetre air-warning equipment for use against both high-flying and low-flying aircraft, and height-measuring equipment (A.W.H. Mark II) which was considered one of its outstanding scientific and technical achievements. It also advised the navy and the R.A.A.F. on Radio Counter-measures (R.C.M.) and designed special detectors for locating or "ferreting out" Japanese radar sets. These detectors were small, resembling an electric torch in size and appearance, and were used by commando groups landing in enemy-held territory.

When employing radar to control interception by fighters it was essential to be able to distinguish friend from enemy. A blip on the radar scope gave no clue to the identity of the aircraft causing it, and to avoid con-

[8] J. W. Hill, BSc, BE. Tutor, Radiophysics Training Course, Univ of Sydney, 1942; Research Officer, Radiophysics Lab, 1942-45. Of Sydney; b. Footscray, Vic, 6 Oct 1921.

fusion a system known as secondary radar was introduced, so named to distinguish it from all the primary systems so far discussed. *A Textbook of Radar* defines a secondary radar system as "one in which a particular object to be located (for example a friendly fighter aircraft) is provided with a combination of receiver and transmitter known as a 'responder' which, when triggered or 'interrogated' by a primary radar emits a characteristic reply signal of its own. The responder not only generates more energy than would be returned by simple reflection, but can be made to provide a coded and hence distinctive signal from which it may be readily identified." In other words, the object being located produced a strong, tagged or labelled artificial echo. About thirty Identification Friend or Foe (I.F.F.) sets were made as part of the ground-controlled interception units. The same principle was used in radar beacons. The responder in such beacons, radiating an identifiable signal much stronger than a natural echo, could provide a radio landmark analogous to a lighthouse. Radar beacons were invaluable for guiding aircraft back to airfields and aircraft carriers. Altogether over 200 beacons were manufactured by the Gramophone Company Ltd.

In producing radar equipment worth millions of pounds for the forces in the South-West Pacific Area, the Australian radio industry, backed by the scientific work of the C.S.I.R., did an excellent job. Using an organisation tooled up originally for the manufacture of broadcast receiving sets, the industry, beginning in earnest early in 1942, made a rapid switch to the manufacture of equipment a great deal more complex and exacting in its requirements. The distinctive feature of this effort was the speed of its accomplishment in the face of all kinds of obstacle that might, on occasion, have been expected to bring it to a standstill: the usual lack of skilled manpower and shortage of materials, secrecy and innumerable tangling regulations. Equipment often went into production while research was still being carried out on the prototype. This frequently meant changing the design half way through the completion of a particular order, which was naturally a source of irritation and worry to the manufacturer. The difficulties experienced were those inherent in any attempt to put manufacturing processes into effect at a speed many times greater than would ever be contemplated in peace time. The wonder of it all was that the difficulties were overcome with so little friction and trouble. Altogether 2,076 items of Service radar equipment and 9,085 items of general radar test equipment were manufactured.

Once the demand for Australian radar equipment had passed, as it did when American supplies arrived in great volume in 1944, the staff of the Radiophysics Laboratory began to devote more and more of its time to fundamental research into the problems of radar.

As early as 1943 a research group under Dr Pawsey and a related mathematical group under Dr Jaeger began to devote most of their time to an inquiry into anomalous propagation or superrefraction, a phenomenon first systematically investigated in Britain in 1943. Radio waves, like light, travel in perfectly straight lines in homogeneous media, but on passing

from one medium to another both kinds of wave undergo a bending, or refraction. Since under normal conditions the lower layers of the atmosphere are physically and optically more dense than the upper layers, radio waves undergo a slight bending towards the earth, but nothing like enough to cause them to follow the earth's curvature.

Water vapour in the atmosphere exercises a strong influence on the behaviour of radio waves. Unusually large amounts of water vapour sometimes occur in the first few hundred feet of the atmosphere and make it optically dense to radio waves. Thus they are bent to such an extent that they may follow the curvature of the earth. This was known as superrefraction and was responsible for the phenomenally large ranges sometimes observed with sets whose normal range was quite small. For example, a set whose normal range for the detection of a ship was only 20 miles might suddenly be able to detect ships at a distance of 200 miles, and in extreme cases at 700 miles. Superrefraction was caused when a mass of relatively cool and damp air underlay warm dry air, a condition often found on the coast of north-western Australia.[1] Here the hot dry wind from the desert blows out over the sea, which cools the lowest layer and makes it moist. Superrefraction may also occur over the land at night when lower levels of the atmosphere are cooled by the rapid cooling of the land on a fine cloudless night. The phenomenon is so strongly developed off Darwin that air-warning sets (1.5 metres) operating there reported echoes from the coast of Timor, 300 to 500 miles away, several times a month. Similar equipment near Broome, Western Australia, reported echoes from the coast of Java, 900 to 1,100 miles away. In February 1944 a high-flying Catalina was followed almost continuously for a distance of 800 miles on its journey from Perth to Colombo by the air-warning station at Geraldton.

A useful addition to our knowledge of superrefraction was made by the R.A.A.F. and army stations round the coasts of Australia and New Guinea which, following the suggestion of research physicists, made daily observations on the phenomenon as part of their regular duty. As with some of the data of meteorology, these observations on superrefraction could hardly have been made in peace owing to the prohibitive cost of maintaining so many stations at isolated points. The observations and their interpretation by the Radiophysics Laboratory were duly published and in this way became a useful by-product of wartime activities.[2]

There can be no doubt that Australian science made one of its most valuable contributions to the war effort by assisting the introduction of radar. That it was able to do so was to a large extent due to the sound foundations laid earlier by the Radio Research Board in training physicists and providing research facilities. The light-weight air-warning equipment in particular filled a vital need that could not have been met in any other way. Few better illustrations could be found of the rewards that may come

[1] F. J. Kerr and J. K. Strachan, Radiophysics Laboratory Report RP 259/1, Aug 1945.

[2] F. J. Kerr, "Radio Super-refraction in the Coastal Regions of Australia", *Australian Journal of Scientific Research*, Series A, Vol. 1 (1948), p. 433.

from scientific research undertaken in the first instance in the pursuit of knowledge alone. The experience gained in war time was embodied in one of the earliest textbooks of radar to be published in English.[3] A collective work by the staff of the laboratory, it went beyond purely Australian achievements in radar, attempting to consolidate knowledge of the subject up to that time—1946.

[3] *A Textbook of Radar* (1947).

CHAPTER 20

THE BUILDING AND REPAIR OF SHIPS

BEFORE the war of 1914-18 there was very little commercial shipbuilding, apart from wooden craft, in Australia; even during the most critical part of that war when the fleets of Allied merchantmen were dangerously depleted by submarine warfare, merchant shipbuilding was limited to a few wooden ships suited only to coastal trade.[1] Late in that war the industry was established on a larger scale. Orders were placed for 20 ships of 5,500 tons deadweight and later for two of 12,800 tons.[2] None of these was finished before the end of the war. Thereafter the merchant shipbuilding industry faded away almost completely, for reasons that were partly technical but mainly economic. The young steel industry could supply only a limited range of steel shapes—sectional parts and steel framings, but not rolled plates, which had to be imported from Britain and the United States. A great many other components also had to be imported. The result was that competition with oversea shipbuilding became uneconomic and shipyards in Adelaide, Newcastle and Maryborough were closed and in some instances dismantled. Ship repairs and docking, mainly of small coastal vessels, became the chief preoccupation of the industry.

When war came in 1939 the country was without any worthwhile merchant shipbuilding industry, though shipbuilding had not been allowed to die out altogether.

A beginning of modern naval shipbuilding had been made in 1911 with the assembly of the destroyer *Warrego*. In 1913 the cruiser *Brisbane* and destroyers *Huon* and *Torrens* were laid down at the Cockatoo Docks, Sydney, and, by 1916, these and also the destroyer *Swan* had been built, and a second cruiser, the *Adelaide,* laid down.

Cockatoo Island, the cradle of the Australian shipbuilding industry, has seen many changes in its control. Its two docks, the Fitzroy and the Sutherland, built in 1858 and 1885 respectively, the former by convict labour, were controlled by the New South Wales Government until 1913. After the establishment of the Royal Australian Navy and the initiation of the above program of naval shipbuilding they were transferred to the Department of the Navy. From 1921 they were controlled by various Commonwealth Government organisations until 1933. They were then leased for a period of 21 years to a private company known as the Cockatoo Docks and Engineering Company Pty Ltd. In taking over the dockyard the com-

[1] The launching of the *Ballarat* at Pyrmont, NSW, in 1854 marked the beginning of steamship building in Australia. Actually the *Ballarat* was built in England and merely assembled at Pyrmont.

[2] The 5,500-ton ships were made by: Commonwealth Dockyard, Williamstown; Navy Department, Cockatoo Island, Sydney; State of NSW, Walsh Island, Newcastle; Walkers Ltd, Maryborough, Qld; Poole and Steele Ltd, Port Adelaide. The 12,800-ton ships were made at Cockatoo Island. The size of a cargo ship was usually indicated by its deadweight, which was her total carrying capacity for cargo, fresh water, crew, baggage, stores and fuel.

pany also took into its employment most of the senior executives and foremen, and many of the accounting and drawing office staffs.

A spasmodic and meagre program of naval construction, under which the seaplane carrier *Albatross* (4,800 tons), two sloops—*Yarra* and *Swan* —lighthouse steamers, the pilot steamer *Captain Cook* and some smaller vessels under 500 tons were built, kept the shipbuilding industry alive between the years 1924 and 1939.

At the outbreak of war in 1939 the Cockatoo Docks were the only large shipbuilding and marine engineering works in the Commonwealth and from them the other shipbuilding establishments set up during the next few years were to obtain much help. The dock's activities were greatly increased about the time of the Munich crisis in order to prepare the navy for the war that by then seemed inevitable. After the cruisers *Australia* and *Adelaide* had been modernised, the construction of two more sloops, *Parramatta* and *Warrego,* was pushed forward with all speed. The four sloops, each with a displacement of about 1,000 tons, were built to Admiralty design and were intended for escort work.[3]

The next undertaking was the construction of four boom-working vessels to the order of the Commonwealth Government, also to Admiralty design. These vessels, the *Kookaburra, Koala, Kangaroo* and *Karangi*[4] intended for harbour defence, were fitted with heavy winches, derricks and ancillary equipment for handling buoys, sinkers, nets and other gear required for the boom defence of Australian harbours.

The shipbuilding industry of the early part of the period between wars had been greatly dependent on imported materials, even steel plates, but fortunately by the time war broke out, the metal industries in Newcastle and Port Kembla had developed to a stage where they could meet most of the requirements of shipbuilding: steel plates and sections for hulls, boiler plates and boiler tubes to the full Admiralty specifications for boilers; large steel castings and forgings, including those for turbine casings and propeller shafts; and finally steel wire rope, sheet steel and steel pipes. The non-ferrous metal industry was able to provide corrosion-resistant condenser tubes of copper-nickel and aluminium-brass and also the bronzes for propellers.

Shortly before war broke out the Navy Office prepared a program of naval construction an important feature of which was the outline design of a corvette, or auxiliary minesweeper, for the local defence of harbours. As it seemed likely that corvettes and other small naval vessels would be required in considerable numbers, plans were made for extending the shipbuilding industry to centres outside Sydney.

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[3] They were 250 ft by 36 ft by 16½ ft, driven by twin-screw, Parson's impulse reaction-geared turbines with two small water tube boilers of Admiralty 3-drum type; their shaft horse-power was 2,200 and speed 17 knots. Armament was one twin 4-in HA gun mounting forward and one single 4-in HA aft, as well as smaller guns.

[4] The dimensions of these vessels were 150 ft by 32 ft by 17 ft; their armament was one 12-pdr HA-LA gun and some smaller guns. The propelling machinery consisted of one set of three cylinder triple expansion engines with two cylindrical multi-tube boilers of the Scotch type. Indicated horse-power was 850 and speed 11½ knots.

In the meantime detailed designs for a prototype corvette, the *Bathurst,* were prepared jointly by Cockatoo Docks and the Navy Office. While the construction of the *Bathurst* was in progress, Engineer Rear-Admiral McNeil,[5] Chief of Naval Construction, who was largely responsible for initiating this program, began organising the shipbuilding industry throughout the Commonwealth in anticipation of a great expansion of its activities. In the next few years old shipyards were revived and new ones were built. Revival was often tantamount to rebuilding. The shipyards at Walkers Ltd, Maryborough, Queensland, for example, had lain idle for 20 years. Derricks and scaffolding had been dismantled and disposed of; timber headstocks and piles forming the foundation of building slips had been covered with silt and undergrowth. This yard, destined in the next few years to make an important contribution to the R.A.N., was little more than an open paddock running down to a tidal river. Under the pressure of the demands of war, all this was soon changed. Building berths were restored; cranes and derricks erected and provision was made for the supply of compressed air and electric power. By April 1940 it was ready to lay the keel of its first corvette, *Cairns.*

In the course of his survey of industry's potentialities for building ships, McNeil had noted the well-equipped workshops of Evans Deakin Ltd at Rocklea near Brisbane, where for many years the firm had carried on such large-scale engineering as the building of bridges, oil tanks and railway waggons. Here were most of the facilities required for fabricating steel for ships. All that was lacking was shipyards. Late in 1939 when approached by the Navy Office the company readily agreed to undertake the construction of naval vessels. To assist the company in its new undertaking the Queensland Government acquired and leased to it a site on the Brisbane River where early in 1940 it began to build an oil-fuel lighter for the R.A.N. While the lighter was being built, extensive excavations were made in preparation for the installation of additional shipbuilding berths, fitting-out yards and wharves. The laying of the keel of its first corvette towards the end of the year marked the beginning of one of the most successful of the new shipbuilding centres.

Another most notable accession to Australian shipbuilding capacity at this time was the establishment by the B.H.P. Company of shipyards at Whyalla, in South Australia. For nearly 100 years after it was first sighted by Matthew Flinders in 1802, the arid region around the western shores of Spencer's Gulf (the annual rainfall averages only 8 inches) had lain desolate and almost devoid of human activity. Then at the turn of the century, with the discovery of great deposits of iron ore at Iron Knob and Iron Monarch, the area became the scene of growing activity. A small port 34 miles from Iron Knob sprang into existence for the shipment of iron ores. First known as Hummock Hill and later as Whyalla, this port became firmly established after the opening of the steelworks at Newcastle in 1915

[5] Engr Rear-Adm P. E. McNeil, CB; RAN. Engr-Manager Garden Island, Sydney, 1922-28; Dir Engineering RAN 1931-40; Third Naval Member and Chief of Naval Construction 1940-43; Dir, Shipbuilding Board, 1943-48. B. Melbourne, 25 Sep 1883. Died 17 Apr 1951.

and for about the next twenty-five years remained more or less static with a population of about 1,000. The second world war saw a remarkable extension in the size of this port to a population of 8,000; this was made possible by the construction of a 223-mile pipeline from the River Murray, which gave the town an assured water supply. The first phase of this expansion was marked by the erection of a large blast furnace, begun in 1938 and completed in May 1941. As part of the program for extending the steel industry to this area, shipping facilities were greatly increased by making a harbour and a deep-water channel approach to it.

About this time Admiral Colvin[6] (First Naval Member) asked the Chief General Manager of B.H.P. (Mr Essington Lewis), whether the company would be interested in building ships. When the proposal was put to the board of directors it was agreed to in principle. It was not long before the principle had involved the company in an expenditure of £1,000,000 on building and equipping a modern shipyard. The Whyalla shipyard incorporated many of the best features of modern British and American shipbuilding practice. With its five slipways, enabling the simultaneous construction of five ships, Whyalla became the largest merchant shipbuilding centre in Australia. All these facilities were built up in a town remote from other industrial centres, where housing for the large influx of workers for this and many other projects had to be provided. The first ships laid down at Whyalla in 1940 were the corvettes *Whyalla, Kalgoorlie, Gawler* and *Pirie,* all of which were launched during 1941.

The shipyard at Walsh Island near Newcastle, which had contributed much to the industry towards the end of the first world war and for some years afterwards, was in no better condition than that of Walkers Ltd. Activity at Walsh Island had died out completely after the great trade depression when much of its plant and many of its buildings were sold. The remainder gradually fell into decay and ruin; building berths became completely overgrown and the whole dockyard was a dreary picture of industrial desolation. When the time came to revive the moribund industry it was decided to re-establish it at Dyke End. Here with much of the equipment that remained at Walsh Island, the building of a modern shipyard (the New South Wales State Dockyard[7]) was begun early in 1942 and before the year was out the keel of the corvette *Strahan* was laid.

For all the shipyards at which corvettes were built Cockatoo Docks served as a centre from which plans, templates and a great deal of technical information of all kinds were disseminated.

Corvettes, as one naval authority put it, were "conceived as substitutes for trawlers, finished up in many respects as substitutes, if not for battleships, certainly for destroyers". In size they represented the result of a compromise frequently necessary in naval construction during a war; they could have been made longer but only at the expense of reducing

[6] Admiral Sir Ragnar Colvin, KBE, CB; RAN. First Naval Member, Aust Naval Board, 1937-41; Naval Adviser to High Commnr for Aust in London 1942-44. B. 7 May 1882. Died 22 Feb 1954.

[7] Mr D. Lyon McLarty was appointed Director of Engineering and Shipbuilding.

the numbers built.[8] While it is doubtful whether corvettes would have been very effective against the larger modern submarine they were well adapted to the original purposes for which they were intended, namely escort work and the local defence of harbours. Corvettes, including their armament and electrical equipment, were built almost entirely from Australian materials.

They were fitted with two water-tube boilers and two sets of reciprocating engines, a type of machinery that could be readily produced by local engineering workshops. Cockatoo Docks, which built the boilers for all corvettes launched in Australia, also built reciprocating engines for its own corvettes; Mort's Docks made the engines for a proportion of theirs; engines for the remainder were built by leading engineering firms in different parts of the Commonwealth: Thompsons Engineering and Pipe Co Ltd of Castlemaine, Perry Engineering Co Ltd of Adelaide, Walkers Ltd of Maryborough, and A. Sargeant and Co Pty Ltd of Brisbane, West Australian Railways, and Hoskins Engineering and Foundry Ltd of Perth. Their armament consisted of one 4-inch gun and some close-range guns which were improved as the war progressed. Fitted first with asdic[9] and later with radar, and equipped to sweep acoustic and magnetic mines as well as contact mines, these vessels—"maids of all work"—did much of the escort work throughout the war.

Corvettes were built by—

Walkers Limited, Maryborough	7
Evans Deakin & Co Ltd, Brisbane	11
State Dockyard, Newcastle	1
Cockatoo Docks & Engineering Co Ltd	8
Mort's Dock & Engineering Co Ltd, Sydney	14
Poole & Steele Ltd, Sydney	7
HMA Naval Dockyard, Williamstown	8
Broken Hill Pty Co Ltd, Whyalla	4

Of these 36 went to the Australian Navy, 20 to the Royal Navy and 4 to the Indian Navy.

Plans for construction of frigates were put in operation towards the end of 1942. These vessels, designed by the Admiralty for anti-submarine work, were much larger and faster and more modern in their asdic and radar equipment than the corvettes. They were equipped with a mortar for throwing depth charges ahead of the vessel, a more effective procedure than dropping them over the stern because it gave the submarine much less time to execute evasive manoeuvres. Like the corvettes they were fitted with water-tube boilers, all of which were built at Cockatoo Docks,

[8] The dimensions were 180 x 31 x 15½ feet; the displacement from 740-790 tons.

[9] Asdic was a remarkably successful device developed by the Admiralty for the underwater detection of submarines. It depended for its action on the reflection of supersonic waves produced by vibrating quartz crystals. Asdic equipment was supplied by Airzone Ltd, Casper Precision Engineering Pty Ltd and Raycophone Ltd.

and reciprocating engines made by Commonwealth Marine Engineering Works at Brisbane and Port Melbourne.

Frigates were built by—

Cockatoo Docks . . .	2
Mort's Dock	4
Walkers Ltd	3
Evans Deakin	2
Williamstown Dockyard . .	2
State Dockyard . . .	1

From a technical point of view, quite the most outstanding piece of naval shipbuilding undertaken during the war was a program of destroyer construction which the Commonwealth Government, late in 1939, entrusted to the Cockatoo Dock and Engineering Co Pty Ltd. Engineer Commander Hutcheson[1] was appointed Principal Overseer to supervise the construction of these vessels. The destroyers, which were identical in design with the famous British Tribal class and were much faster, more powerful and more complex in structure than any ships previously built in Australia, contained a high proportion of locally produced materials. The Australian Tribal Class destroyers—*Arunta* (1942), *Warramunga* (1942) and *Bataan* (1945)—were to uphold the high traditions of their class. The *Arunta* and the *Warramunga* served in the Pacific and won high praise for their fighting efficiency and their ability to withstand the most arduous conditions of service. The third vessel, named *Bataan* as a compliment to the Americans, was launched by Mrs Douglas MacArthur. Owing to the pressure of urgent work on the repairing of war-damaged vessels *Bataan* was not launched until late in the war, but she was completed in time to take part in the final operations against Japan.

These vessels were 355½ feet by 36½ feet by 21½ feet with a displacement of about 2,000 tons.[2] Their armament consisted of six 4.7-inch, two 4-inch HA guns and a number of smaller guns, and four 21-inch torpedo tubes. Their engines were capable of developing a shaft horse-power of 45,000 and a speed of 36½ knots. The electrical fitting out of each vessel involved a great deal of work, much of which went into the installation of radio and radar equipment.

The boiler shop on Cockatoo Island manufactured all except 12 of the 175 boilers built for naval vessels during the war. Mainly of the three-drum water-tube type, they ranged from those capable of developing 15,000 indicated horse-power (shaft) used in the Tribal Class destroyers, to the 870 indicated horse-power boilers used in the corvettes.

From a technical point of view one of the main consequences of the building of small naval vessels in large numbers was that it re-established

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[1] Engr Capt G. I. D. Hutcheson, BE; RAN. (HMAS *Australia* 1918.) Principal Overseer, Cockatoo Island Dockyd, 1939-43; Engr Mngr, HMA Dockyd, Garden Island, 1943-45; Dir Engineering (Naval) 1945-47; Mg Dir Cockatoo Docks and Eng Co Pty Ltd since 1947. B. Coleraine, Vic, 9 Jun 1897.

[2] These data have been taken from *Cockatoo Docks War Record.*

the shipbuilding industry in Australia and trained men needed for other shipbuilding work—the building of merchant ships and, what proved to be even more important, the repair of ships of all kinds.

Early in the war Germany's intensive submarine campaign began seriously to deplete Britain's merchant navy and to tax to the uttermost the capacity of her shipyards to repair damaged and replace lost ships. In these circumstances it was natural that the Commonwealth Government, though well aware that it could not do much by comparison with Britain and that much of its resources had already been committed, should consider the possibility of re-establishing a merchant shipbuilding industry in Australia. As a preliminary step the War Cabinet asked the Board of Business Administration and Rear-Admiral McNeil to make a joint report on the action necessary to launch a merchant shipbuilding program. This report was presented on 13th January 1941. Shortly afterwards—on 27th March 1941—the Government set up the Australian Shipbuilding Board whose functions were to design vessels, to call tenders and place orders, to coordinate supplies to shipbuilders, to supervise construction, and to accept vessels after sea trials. It was also responsible for the repair and maintenance of all merchant ships and the provision of dry-docking facilities.[3] One of the first questions the board had to decide was what kinds of ships were to be built. McNeil had already given some thought to this question in his report.

In an attempt to make up for the heavy losses of merchant shipping the United Kingdom sent a purchasing mission to Canada and the United States to arrange the construction of a type of ship whose simple design would permit it to be built quickly and in large numbers. From its inquiries there emerged the Liberty Ship program, in which Australia was asked to participate. However the Australian Shipbuilding Board, in the belief that the construction of ships of about 10,000 tons was as much as could be reasonably undertaken locally, declined the invitation. It was more inclined to accept the suggestion of the British Ministry of War Transport that Australia should undertake the construction of a ship similar to the *Scottish Monarch,* a type designed by the Caledon Shipbuilding and Engineering Company of Dundee. After careful consideration and long discussion with the Construction Branch of the Department of the Navy the board decided that a standard vessel of this type was well within the capacity of Australian industry. Standardisation, even if it was confined to the hull, offered considerable advantages in economy of construction. The *Scottish Monarch* represented the best compromise between conflicting requirements except

[3] The members of the Board were: The Hon F. P. Kneeshaw until Oct 1943, then N. K. S. Brodribb, Contr-Gen of Munitions Supply, Chairman; Engr Rear-Adm P. E. McNeil (Dir of Shipbuilding); S. W. Griffith (finance member); A. S. McAlpine (employees' member); A. Percival (Chairman of the old Aust C'wealth Shipping Bd) became a member in Aug 1941; A. L. Nutt (resigned 17 Feb 1945), Secretary, replaced by J. C. M. Merrilees as Acting Secretary. During the absence abroad of the Dir of Shipbuilding, H. P. Weymouth was appointed Acting Director. Technical staff of the Board comprised: H. P. Weymouth, Production Engineer (later Chairman and General Manager); C. W. J. Barker, Supervising Naval Architect; A. Macaulay, Chief Engineer Draughtsman (later promoted to Supervising Marine Engineer); M. H. Stevens, Electrical Engineer.

for one thing—its maximum speed of 10 knots was too slow. Experience had shown that a little more speed made ships much safer from submarines, and the Australian Shipbuilding Board altered the design of the *Scottish Monarch* to give it a finer underwater form and more power, and consequently greater speed.

The *Scottish Monarch* type of merchant ship as modified for construction in Australia was a single-screw, shelter-deck steamer with five holds, the main bulkheads of which were carried up under the shelter deck for additional safety. It was propelled by steam reciprocating, in combination with exhaust turbine, machinery designed to develop 3,500 indicated horsepower and to operate with coal or oil fuel fired water-tube boilers fitted with superheaters. Other important details of the ship were—

Cargo capacity: 7,600 tons approximately (for a voyage of 13,000 miles from Australia to the United Kingdom).

Dimensions: 447 feet by 56 feet.

Speed: 12 knots.

In making the decision to build the *Scottish Monarch,* or as it came to be known locally the "River" or "A" class type of cargo-carrying ship, the Australian Shipbuilding Board had clearly in mind the results of its survey of existing shipyards and engineering shops throughout Australia. This showed that, with the exception of those at Cockatoo Island and Whyalla, Australian shipyards would not be able to undertake the construction of "A" class merchant ships without building larger berths, workshops, machine tools, heavy cranes, derricks and other equipment and providing electric power for welding and compressed air for pneumatic tools. The board was also aware that the construction of both naval and merchant vessels could only be achieved if the industry were given high priority in the use of labour, materials and engineering resources. The original intention was to construct 60 "A" class ships at the rate of 12 a year. Since about one-third of the work involved in building a merchant ship (and for that matter a naval ship) was usually done in establishments outside the shipyards, careful coordination of the engineering requirements of general defence work and shipbuilding was necessary. Approximately 400 different firms contracted to supply 1,200 different items for an "A" class ship.

Building the hulls presented less difficulty than the production of engines, boilers and auxiliary equipment. In point of fact the capacity of Australia to build ships was limited by that of her engineering workshops to build marine engines. When the Shipbuilding Board was formed the existing facilities could not provide more than about one-third of the combined requirements of the naval and merchant shipbuilding programs. Inability to produce marine engines in the necessary numbers was due almost entirely to the lack of modern, heavy machine tools for making engine parts and the lack of suitable workshops for assembling the engines. The combined shipbuilding programs called for the annual construction of 12 reciprocating engines of 3,000 indicated horse-power for the "A" class

merchantmen and approximately three times as many similar but smaller (2,750 horse-power) engines for corvettes. There was only one way to solve this problem and that was to build special annexes for making marine engines. On 17th June 1941 the Minister for Munitions approved the construction of two annexes. As there were already two marine engine shops in Sydney (at Cockatoo Docks and Mort's Dock) it was decided to build the two new ones (costing approximately £250,000 each) in Melbourne and Brisbane respectively, the first Commonwealth Marine Engine Works being established at Port Melbourne, and the second alongside Messrs Evans Deakin and Company's works at Rocklea, Queensland. Main engines for merchant ships were also built at the Australian Iron and Steel Works at Port Kembla, the N.S.W. Government Engineering and Shipbuilding undertaking at Newcastle (usually called the State Dockyard), and the B.H.P. Co Ltd at Newcastle.

Notable advances were made in the construction of large marine engines during the war. Economy in construction and the high quality of materials and workmanship in the steam engines constructed in Australia in this period enabled this phase of the shipbuilding industry to withstand oversea competition after the war. In the 9,000-ton steamers, water-tube boilers burning coal on mechanical stokers or alternately fuel oil, supplied steam at 240 pounds per square inch to triple expansion steam engines and exhaust turbines of the Bauer Wach type. Under light ship trial conditions the turbines added about 25 per cent to the power previously developed by the reciprocating engine.[4] They also added considerably to the speed, or at normal service speed permitted a reduction in the fuel consumed. As the exhaust turbine had to operate at 3,500-4,000 revolutions per minute it was necessary to use large reduction gear boxes to reduce the speed of 85-95 revolutions per minute of the main engine.

Manufacture of the exhaust turbine and reduction gear-box was by reason of their size and the precision required, the most difficult technical operation undertaken by the shipbuilding industry. Construction of the turbine was the work of Cockatoo Docks and Engineering Co Ltd, and Thompsons Engineering and Pipe Co Ltd (Castlemaine, Victoria); the latter company supplied most of the castings and forgings for the construction of the reduction gears. Messrs John Welch (Melbourne) carried out the gear cutting with special machines supplied by the Australian Shipbuilding Board and, after machining operations were completed, assembled the complete gear-box.

By the time the merchant shipbuilding program was ready to begin most of the machine shops in the capital cities had been caught up in work for the Department of Munitions, so that much of the less complicated but often no-less-essential machinery required by the Shipbuilding Board had perforce to be manufactured in outlying centres of the Commonwealth.

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[4] H. P. Weymouth, "Australian Shipbuilding and Marine Engineering", *Journal of the Institution of Engineers*, Dec 1951, p. 231.

Machine shops in the sugar-cane growing centres of Northern Queensland previously engaged in repairing machinery for sugar mills, made windlasses and winches. The Railway Workshops at Ipswich, Queensland, and Midland Junction, Western Australia, cast bronze propellers though they had never before attempted this kind of work. Small shipyards in Western and South Australia made many hundreds of life-boats. In no other wartime undertaking did so many widely separated centres participate as in shipbuilding.

During the period 1943-46 thirteen 9,000-ton "A" cargo ships were laid down and completed as follows:

Cockatoo Docks and Engineering Co Pty Ltd	2
Evans Deakin and Co Ltd	4
The Melbourne Harbour Trust Commissioners, Williamstown	2
Broken Hill Pty Co Ltd, Whyalla	5

In the middle of 1942 Japanese submarines began to attack merchant shipping on the eastern Australian coast, concentrating on vessels carrying iron ore from Whyalla to Newcastle and on vessels carrying finished steel products and coal from Newcastle to Melbourne. Several of the B.H.P. Company's ships were sunk. To replace these vessels the company first built two Chieftain class freighters: the *Iron Monarch* which was launched on 8th October 1942 and commissioned on 12th April 1943, and the *Iron Duke* launched on 3rd May 1943 and commissioned on 1st August 1943. These vessels, specially designed for carrying iron ore, were of about 8,000 tons deadweight.

That Whyalla was able to make so substantial a contribution to the merchant ship program was largely because, apart from the earlier construction of naval patrol vessels, it was able to devote all its energies to shipbuilding; being so far from the main bases it was not called on to do any of the repairs with which the other dockyards were flooded.

Although, under the circumstances, the building of thirteen "A" class ships which were about 98 per cent Australian manufacture and material was no mean achievement, it fell far short of the total of sixty ships originally planned. As will appear in the sequel there were several good reasons for this. The Japanese attack on coastal shipping, the diversion of labour and materials to repair of ships, and the construction of small craft caused the Australian Shipbuilding Board to curtail its plans for the largest freighters and to attempt the building of smaller "D" class (3,000 tons) coastal freighters. The other demands were so great however that very little was done. A few "D" class ships were laid down towards the end of the war but the first, *Dorrigo,* was not handed over by the State Dockyard until May 1946.

In order to bring Tasmania and Western Australia into the shipbuilding program the Australian Shipbuilding Board decided to undertake the construction there of 32 wooden 300-ton merchant ships. Designs for these ships (and many other small craft) were prepared by the Navy Office. The choice of wood as a material of construction was dictated by the fact

that while both States were distant from sources of steel, they did possess shipyards suitable for the building of wooden ships. It was originally intended that these ships should go to the Department of Commerce, but they were finally allotted to the army.

Measuring 125 feet by 12 feet 6 inches and designed to carry 300 tons of dead weight, the ships were propelled by 136-200 h.p. diesel engines which, owing to the difficulty of importation, were manufactured in Australia. Their cruising range at 8 knots was 1,500 miles. By the end of the war 22 vessels, 6 of them provided with 7,750 cubic feet of refrigerated space, had been delivered to the army: ten from the Glenorchy Shipbuilding Yard at Prince of Wales Bay, Tasmania, and 12 from North Fremantle, Western Australia.

For the first two years of the war a considerable part of the resources of shipyards was applied to the conversion of merchant ships to troop transports, hospital ships and armed merchant cruisers. Beginning late in 1939 Cockatoo Docks in a little over a month converted the liners *Orion, Orford, Orcades, Otranto* and *Strathnaver* to transports for the first convoy of Australian troops to the Middle East.

After the first convoy left, large liners such as the Canadian Pacific *Empress of Japan* and *Empress of Canada* began to visit Sydney, and each in turn had its accommodation modified and increased. Then came the very large liners *Aquitania* and *Queen Mary*. Conversion of the latter as she lay moored in midstream in Sydney Harbour was carried out in the amazingly short period of 14 days. Immediately it was completed she sailed with 5,000 Australian troops for Malaya. A little later the *Queen Elizabeth,* which had left the Clyde Shipbuilding yards before completion owing to the outbreak of war, reached Sydney Harbour where, like her sister ship, she was converted as she lay anchored in midstream. No berth in Sydney Harbour could accommodate her. Within a short time she took her place in convoy with other great liners making what was in effect her first voyage as a passenger liner, carrying 5,600 Australian troops overseas.

These were but a few of the conversions; others included Dutch liners, the *Nieuw Holland* and *Nieuw Amsterdam,* the French liner *Ile de France* and the Australian interstate ships *Zealandia, Ormiston* and *Katoomba.* In Cockatoo Docks alone 250 ships were altered. Conversions involved not only increasing the number of berths but also a proportional increase in catering and other facilities.

The liners *Manunda* and *Oranje* (one of the most modern of the Dutch ships) were fitted out and equipped to a high standard as hospital ships to carry about 300 and 700 patients respectively.

Plans made before the war provided for the rapid conversion of a number of merchantmen to armed merchant cruisers. It was in the conformity with these that immediately after the outbreak of war work was begun on conversion of the *Moreton Bay* (at Cockatoo Docks), *Arawa* and *Westralia* (at Mort's Dock), and *Manoora* and *Kanimbla* (at Garden

Island). These conversions were extensive and involved fitting several 6-inch guns, fire control, protected magazine, ammunition supply, magazine flooding and searchlights as well as rearrangement of the accommodation. Later in the war (1943) the *Manoora, Kanimbla* and *Westralia* were altered at Garden Island for use as landing ships for the infantry. For this purpose they proved most successful; they took part in most of the major landings in the South-West Pacific Area where they were used both by Australian and United States forces.

All important merchant ships were armed—mostly with 4-inch guns, except the large liners which were given more elaborate protection in the form of 6-inch and anti-aircraft guns. Although some ships had in the course of construction been appropriately strengthened in anticipation of the day when they might have to be armed, most had not. Consequently extensive structural alterations were usually required when fitting armaments. During the war more than 1,000 guns were fitted to over 300 ships, mainly in Sydney.

In addition to the major conversions, many small harbour craft—ferries, dredges, tugs and self-propelled barges—were converted to floating cranes, mobile workshops and broadcasting ships for advanced areas in the Pacific.

In the first few months of the war the Germans began to use a type of mine which, after being laid on the floor of the sea, exploded when a ship passed in its vicinity. This was the magnetic mine, detonated not by contact but by an alteration in the strength of the vertical component of the earth's magnetic field caused by the close proximity of a steel ship. Fortunately scientists of the Admiralty Research Laboratory had for many years been studying the magnetism of ships.[5]

That a steel ship behaved as a magnet had in fact for long been the basis of a means for detecting the presence of a submerged submarine. Such a vessel passing over or near a guard loop of wire placed, say, on the sea bed at the entrance to a harbour, induced within the loop a small current which could be readily detected by a sensitive galvanometer. A system like this guarded the entrances to the principal Australian harbours throughout the war.

Admiralty scientists soon discovered how the German magnetic mine worked and how to counteract it. Counter-measures were of two kinds: those designed to destroy the mine by exploding it at a safe distance from the minesweeper; and those designed to demagnetise a ship in such a way that it could pass close to a submerged mine without exploding it. Some of a ship's magnetism—that acquired during its construction—was permanent; some of it changed with the changing position of the ship in the earth's magnetic field. To demagnetise or "degauss" a ship electric currents were circulated through coils of wire so placed that their magnetic field cancelled that of the ship. The aim was not so much to cancel completely

[5] Magnetic mines had in fact been devised for the Admiralty during the first world war under the direction of F. E. (later Sir Frank) Smith, Superintendent of Electrical Dept, National Physical Laboratory. See J. G. Crowther and R. Whiddington, *Science at War*, H.M. Stationery Office (1947).

the ship's magnetic field, as to cancel the vertical component since it was this that caused a magnetic mine to explode. Part of this vertical component was more or less permanent; part varied with the geographical location of the ship. The disposition of the coils and the strengths of the electric current necessary to degauss a ship could only be decided after studying the ship's magnetic field. In order to measure this field a ship was sailed back and forth at known speeds over a loop of wire spread out on a level area of the sea bed.

Owing to the variation of a ship's magnetic field with its distance from the magnetic equator, it became necessary to study the magnetism of ships in different parts of the world. Early in 1940 Dr D. M. Myers, who happened to be in England making preparations for setting up the Electrotechnology Section within the National Standards Laboratory, was asked to take up the study of degaussing on the lines being developed by the Admiralty, so that on his return he could assist the navy to carry out similar work in Australia. In the meantime Professor Madsen placed the facilities of the Radiophysics Laboratory and of the Electrical Engineering Department of the University of Sydney at the navy's disposal for work on degaussing. While awaiting the arrival of special equipment from the Admiralty, electrical engineers of the Radiophysics Laboratory and the Sydney County Council collaborated in the design and manufacture of fluxmeters for measuring magnetic field strength. Preliminary studies were made of the magnetism of a small tug, and a magnetic range was set up in Sydney Harbour. By the time this work was completed Myers had returned to Australia.

In due course magnetic ranges were set up near Melbourne, Fremantle, Brisbane and Adelaide, and with the help of university physics departments in the different States Australia began to participate in the world-wide scheme to degauss British (and later American) ships wherever they were operating. The plan was to keep as continuous a record as possible of a ship's magnetism by "ranging" it each time it entered and left an important harbour. In Sydney alone a team of ten assistants under Commander Reilly[6] recorded and analysed the magnetic fields of all classes of ships entering and leaving the harbour. Similar groups worked in other States.

If a ship had not already been degaussed the operation was carried out on the basis of the analysis made in the Australian port. Measurements made on ships that had already been degaussed, in the United Kingdom, for example, were used to make adjustments necessitated by the ship's new position in the earth's magnetic field. Changes in magnetism that occurred when a ship passed from northern to southern latitudes were rather complex and made it necessary to continually check earlier settings of degaussing coils. A considerable body of information was accumulated from different parts of the world on the basis of which it became possible to formulate empirical rules enabling the prediction of the magnetic behaviour of ships in different circumstances. Degaussing such large ships

[6] Cdr W. L. Reilly, BEE; RAN. (HMAS *Australia* 1917 and HM ships 1918.) Engineering and Construction Branch RAN 1939-45. Of Newtown, Vic; b. Geelong, Vic, 13 Mar 1899.

as the *Queen Mary* offered some difficulties. Owing to their size they could not be ranged on the usual way in Sydney Harbour; instead, divers were sent down with instruments to explore the magnetic field of the ship while it was stationary.

By the end of 1942, when the peak of these activities had been passed, hundreds of ships had been ranged and degaussed or checked. Also, many hundreds of ships, including oversea ships, were fitted with paravanes made in Australia, which protected them against ordinary mines.

It is of interest to record that the entrance of the Japanese midget submarines into Sydney Harbour on the night of 31st May 1942 was not recognised on the automatic recorder at the time. An examination of the record after the event did, however, disclose small variations on the magnetic field of the detecting loop commensurate with the size of the submarine and therefore too small to be detected except by careful scrutiny.

As a result of intensive research on methods of detecting underwater objects, Britain had by 1939 developed anti-submarine equipment far in advance of that possessed by any other nation. Since they could not penetrate water to any extent, high-frequency radio waves such as those used in radar were useless for detecting underwater objects. High-frequency (ultrasonic) sound waves, on the other hand, which travelled readily through water, could be adapted to this purpose. The successful equipment, known as "asdic" consisted essentially of a source of ultrasonic waves generated by a quartz crystal (set in oscillation by the piezo-electric effect) and a means for detecting and measuring the intensity of reflected ultrasonic waves. Before the war all equipment of this kind used by the R.A.N. was made in Britain, but after the middle of 1940, in keeping with the general trend, it was decided to make it locally.

Progress was slow at first, partly because of delays in obtaining specifications from the Admiralty and some essential items that had to be imported, and partly because of the need to redesign some units of the equipment to suit locally-made components and materials. The major contracting firm, Airzone (1931) Ltd of Camperdown, N.S.W., built a special factory for this work and with the cooperation of a large number of other firms (150 in New South Wales and 20 in Victoria) succeeded in manufacturing over 200 sets of asdic equipment (A/S 128) which were installed in destroyers, frigates, corvettes, sloops and minesweepers.

An essential step towards victory in the Pacific was to control that vast area totalling 64,000,000 square miles, or more than three-eighths of the world's sea surface. Control involved more than winning sea battles; it meant keeping lines of communication open for merchant vessels, and this in turn entailed maintaining and repairing large numbers of warships, merchantmen and transports. As the war in the Pacific developed, more and more ships of all kinds needed repairs. In fact the rate at which ships could be repaired seemed to be one of the factors likely to determine the duration of the war in the Pacific. For this reason repair and mainten-

ance of ships in Australia took precedence over building of ships; it was essential to keep the existing fleets in operation. The great distance of the shipyards on the west coast of North America from the theatres of war reduced the contribution they might otherwise have made and threw a correspondingly greater responsibility on Australia. Thus the docks on the eastern seaboard, more especially those of Sydney, were called upon to make a large contribution towards keeping the combined Australian, British, American, Dutch and French fleets, as well as hundreds of merchant ships operating in the South-West Pacific Area, in good running order and repair. Before the war not even the most optimistic engineer would have believed this possible and it could not have been done had the Department of the Navy and the Australian Shipbuilding Board not provided the necessary reserves of machinery and materials. Shipyards had been revived and had been induced to tool up and undertake the manufacture of auxiliary machinery, anchors, anchor cables and many other items they would not otherwise have contemplated. They were therefore ready when repairs began to come in.

Though ships were often repaired at wharves, dry docks were essential for work below the water line. There were dry docks at Cockatoo Docks, Mort's Dock, the N.S.W. State Dockyard, H.M.A. Naval Dockyard, and at Duke and Orr's Amalgamated Dry Docks Ltd in Melbourne. Only the first two establishments possessed docks (the Sutherland and Woolwich respectively) large enough for cruisers, light fleet carriers and large merchantmen. At each of these dockyards there were suitably equipped repair shops, but these needed considerable extension to meet the demands subsequently made upon them.

Not long after the Munich crisis the Commonwealth Government began to consider the possibility of constructing a dry dock capable of accommodating the largest capital ships and merchantmen afloat: this despite the fact that at Singapore, about 4,600 miles away, there was already in existence a dock of the kind contemplated, and despite the fact that Australia owned no capital ships.

> The envisaging of a capital ship dock for Australia was a recognition of the extent to which the defence of the Commonwealth depends, and must always depend on Sea Power. This island continent itself has 12,000 miles of coastline. Its geographical position makes the sea at once its rampart and its weakness. If the ocean highways linking us with the rest of the world can be policed and protected, then our security from operational invasion is assured. If those highways come under enemy domination then we are constantly and directly menaced.[7]

Capital ships and aircraft carriers were among the most potent agents in the exercise of sea power but without facilities for their maintenance and repair in Australia they could not be made fully effective in the adjacent oceans. Quite apart from defence, advantages were to be gained

[7] Admiral Sir Guy Royle, Chief of Naval Staff, *Introduction to the Story of the Graving Dock*, published by C'wealth Govt to commemorate the opening of the dock on 24 Mar 1945 by the Governor-General, HRH the Duke of Gloucester.

if by having all the facilities necessary for their maintenance and repair, it was possible to attract large merchant ships to Australia.

At the beginning of 1939 the Commonwealth Government, having decided that the construction in Australia of a large graving dock capable of handling capital ships would be a vital contribution to Australian and Empire defence, invited Sir Leopold Savile[8] of the British engineering firm of Sir Alexander Gibb and Partners to furnish a report on the most suitable locality for such a dock. The engineering requirements called for:

(*a*) a level site of adequate area to be obtained either by excavation or reclamation;

(*b*) satisfactory foundations, preferably of rock at a reasonable depth;

(*c*) a navigable channel 800 feet wide with a depth of water not less than 45 feet at mean high water of spring tides maintainable at a reasonable cost of dredging if necessary;

(*d*) repair shops sufficient for all likely contingencies with adequate supplies of skilled labour at a convenient distance from the dock;

(*e*) a repair and fitting-out wharf available or readily provided.

The dimensions of the dock finally decided upon were:

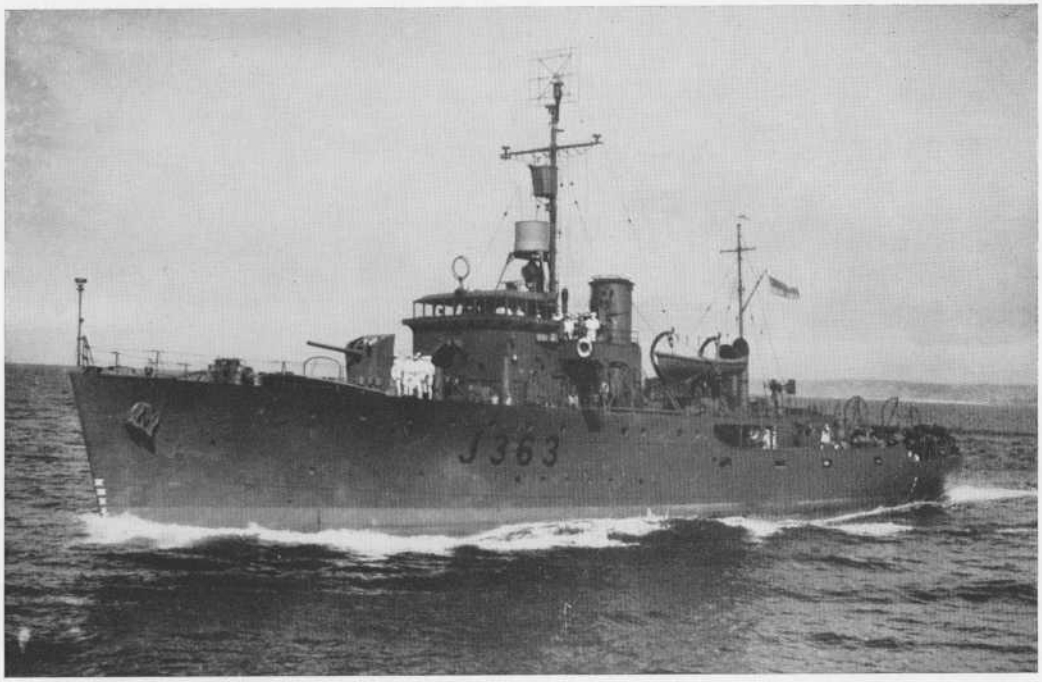
Width at cope level	145 feet
Length, from entrance to cope at head	1,177 feet
Depth (of water over keel blocks at mean high water of springs)	45 feet

The dock had to be easy of access and adjacent to a protected anchorage. Strategical considerations had also to be taken into account. Sixteen different localities were considered but only three were found to conform to any reasonable degree with these stringent requirements. In a report to the Government on 30th January 1940 Savile finally recommended a site between Garden Island and Potts Point, about one mile below the Sydney Harbour Bridge. His recommendation was adopted and approval for building the dock was given by the War Cabinet on 21st May 1940. Later, on 4th July, it was decided that the Minister for the Interior should be responsible for the execution of the work and a Dock Construction Section under Mr Mehaffey[9] was formed to control and coordinate the whole of the construction operations. It was also arranged that Sir Alexander Gibb and Partners should prepare all the required plans and specifications in close liaison with the Admiralty and that the major civil engineering sections of the project should be undertaken by instrumentalities of the State of New South Wales. In this way the Government became committed to the greatest civil engineering project so far undertaken in Australia.

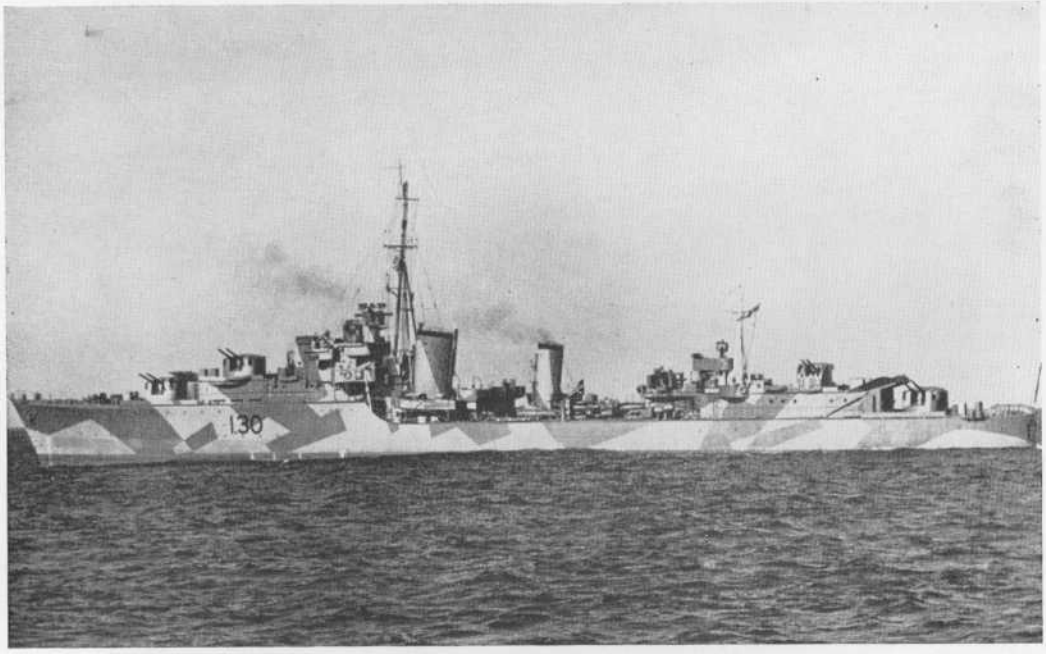
Since it was an instruction of the Government that the design of the dock should be approved by the Admiralty in all essential requirements, the closest liaison was maintained between the Admiralty and the firm

[8] Sir Leopold Savile, KCB. Civil Engineer-in-Chief, Admiralty, 1919-32. Harbour, dock and railway engineer; b. 31 Aug 1870. Died 28 Jan 1953.

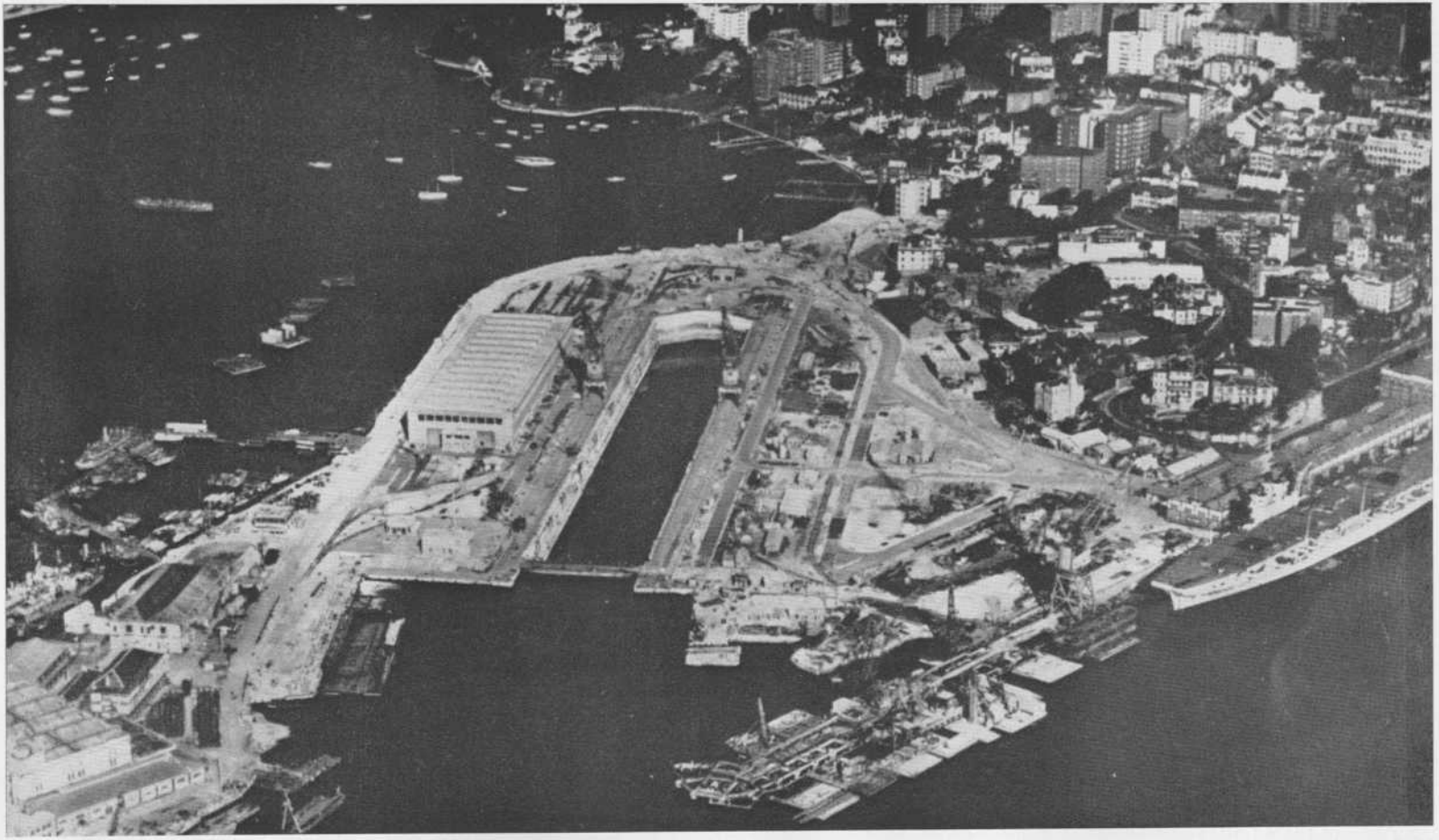
[9] M. W. Mehaffey, BE. Asst C'wealth Dir-Gen of Works 1939-46; directed construction of Capt Cook Graving Dock, Sydney, 1940-46; C'wealth Dir of Works NSW 1946-49. Of Sydney; b. Invercargill, NZ, 17 Dec 1884.



H.M.A.S. *Strahan,* Corvette. (*R.A.N.*)



H.M.A.S. *Arunta,* Tribal Class Destroyer. (*R.A.N.*)



The Captain Cook Graving Dock from the air. (*M. W. Mehaffey*)

of consultants, in particular with Mr Guthrie Brown,[10] who designed the dock and supervised its construction.

The site chosen lay almost entirely below high water. Soundings taken over the area indicated that the sea bed was only 25 to 30 feet below mean low water of springs so that some excavation would be necessary. Examination of about 200 3-inch test bores taken by a diamond drill disclosed that below a layer of about 5 feet of silt there was a firm foundation of sandstone. The first large-scale piece of work was to construct an embankment, or coffer dam, enclosing an area of about 33 acres, within which to build in the dry the concrete body of the dock and some other essential sections of the project. The construction of the embankment began in December 1940.[1]

In order to provide material for the embankment the Public Works Department of New South Wales opened up a new quarry at Balls Head from which a little under 500,000 cubic yards[2] of sandstone were taken. The embankment consisted of stone banks with a core of about 500,000 cubic yards of clay, through which interlocking steel sheet piles were driven to rock for most of the length of the banks. While the coffer dam was being built by the Maritime Services Board of New South Wales, the bulk of the soft material overlying the site on which the concrete body of the dock was to be erected, was removed by dredging. By January 1942 the enclosing embankments were completed, and the Sydney Metropolitan Water, Sewerage and Drainage Board began to pump on 17th February. It took almost two months to drain the enclosed area. Once the water had been removed it was necessary to excavate rock and other materials to secure a sound rock foundation at the depth required, on which to build the concrete walls and floor of the body of the dock. A special concrete capable of resisting the attack of the sulphates in seawater and developing but little heat on setting was used wherever large masses of concrete had to be formed.

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[10] J. Guthrie Brown. Partner of Sir Alexander Gibb and Partners; member of advisory panel on development of Bailey Bridge; technical adviser to North of Scotland Hydro-Electric Board. Consulting engineer; of London; b. Uddingston, Scotland, 22 Apr 1892.

[1] Of the State departments and instrumentalities of New South Wales which cooperated with the Commonwealth Government in the construction of the project, the Metropolitan Water, Sewerage and Drainage Board under its President, Dr T. H. Upton, and its Engineer-in-Chief, Mr S. T. Farnsworth, dealt with the draining of the coffer dam, the execution of the dock itself, the pump house, power house and a number of ancillary works. The Maritime Services Board built the coffer dam, the fitting-out wharf, the foundations for the 250-ton crane, constructed the tail blocks and carried out the dredging under the direction of its Engineer-in-Chief, Mr A. J. Debenham, and the Principal Assistant Engineer, Mr C. R. Bickford. The State Public Works Department under Mr S. B. Jones, Principal Engineer for Water Supply and Sewerage, and Mr H. F. Searl, Principal Engineer for Harbours and Rivers, provided the stone for the coffer dams and carried out various ancillary works. The New South Wales Railways, the Sydney County Council Electricity Undertaking, the Sydney City Council and the State Water Conservation and Irrigation Commission also cooperated with the Commonwealth. Mr J. Muir was principal assistant to Mr Mehaffey throughout the scheme.

[2] The total quantities of material used during the construction of the dock were as follows:

Rock filling in coffer-dam embankments	441,000	cu yds
Clay hearting to coffer dam „	338,000	„ „
Steel sheet piling in embankment	163,500	linear ft
Total length of sheet-piled cut-off	4,089	„ „
Dredging within coffer dams	337,000	barge tons
Excavation for dock excluding prelim dredging	413,000	cu yds
Concrete in dock and pump house, powerhouse and substations	314,000	„ „
Plywood for shuttering	380,000	sq ft
Reinforced concrete piles	45,415	linear ft
Timber piles	41,469	„ „

As the walls of the dock began to rise the whole area within the embankment presented an amazing sight. All day and throughout the night in the blaze of a myriad lights which contrasted strikingly with the blacked-out city, thousands of men laboured in a scene of almost bewildering activity. Bulldozers, scoops, steam shovels and pile-driving machines combined their characteristic sounds to produce a symphony of work and power. From a concrete-mixing plant which turned out 2,000 cubic yards a day came an endless stream of small, snub-nosed locomotives chugging along elevated railway tracks and drawing a line of skips filled with freshly-mixed concrete. As they emptied their contents into moulds the walls forming the body of the dock grew slowly upwards. This concrete body was the largest section of the work: walls of an average height of 70 feet and thickness of 24 feet were built in 40 feet lengths with gaps of 5 feet between them. Concrete was not poured into the gaps until after the lapse of 8 to 12 weeks, when most of the shrinkage in the 40-foot blocks had taken place. The result of this procedure was that the completed walls showed no sign of cracks or leaks. Within the walls of the dock two subways running the entire length of the walls were formed, the upper carrying the fire and fresh water services, the compressed air mains, and the cable which distributed electric power to the various services throughout the dockyards. In the lower subway there was a 21-inch salt-water main for supplying ships in dock.

While the body of the dock was being constructed, activities more akin to those of a shipyard were going on in the neighbourhood where floating caissons, which were the gates of the dock, were being built. Designed by Messrs Vickers Armstrong of Barrow-in-Furness and built by the Sydney Steel Company Pty Ltd, the caissons were of welded steel construction and were fitted with buoyancy tanks, tidal chambers and ballast tanks for sinking and floating. Their construction was undoubtedly the most difficult welding operation undertaken in Australia up to that time. Two were built so that, if necessary, the dock could be worked in two sections. Because there were no suitable launching facilities available on which to build them they were constructed within the area enclosed by the coffer dam to the north of the concrete body of the dock. Each caisson contained enough steel to build the hull of a 10,000-ton ship.

Late in 1944 when the caissons were ready to be floated, when underground substations and other structures were complete and the filling between the dock walls and the enclosing embankment was well above high-water level, water was admitted into the unfilled enclosed area to the north of the dock and into the dock itself. The caissons then became waterborne. Since, when in light draft, a caisson drew more than 30 feet—a draft greater than that of the launching draft of the largest vessel at the time—it would have been impracticable to float it in any other way unless a special slipway had been built for the purpose. By means of three 60-inch centrifugal pumps constructed of a corrosion-resisting alloy of nickel and iron and designed to discharge 70,500 gallons per minute against a head

of fully 50 feet, the dock could be emptied of its 50,000,000 gallons of water in about four hours.

The dock itself was sufficiently near completion early in 1945 to be used by the British Pacific Fleet on its arrival in Australian waters for the final drive on Japan. It was officially opened on 24th March 1945 by the Governor-General, the Duke of Gloucester. Before the end of the year eight capital ships of the Pacific Fleet—*Illustrious, Indomitable, Duke of York, Anson, Implacable, Formidable, Indefatigable* and *King George V* —had been docked.

While the construction of the dock was acclaimed as an outstanding Australian engineering achievement,[3] Britain's vital contributions must not be overlooked. In addition to the design of the dock and the preparation of all the plans and specifications, practically all the machinery for permanent work on the dock was supplied from Britain, and in spite of the hazards of enemy action there and on the long voyage out to Australia it was delivered at the site of the dock before it was actually needed. Only two shipments were lost.

The strategic importance of Brisbane, the Australian port nearest to the west coast of America on the great circle route, was enhanced with the extension of war to the Pacific. At one stage it appeared likely that Brisbane would be near the front line, and it became obvious that every effort should be made to provide major dock facilities.[4] In August 1942 the Coordinator-General of Public Works, Mr Kemp,[5] was entrusted by the Queensland Government with responsibility for the construction of a dock to be known as the Brisbane Graving Dock. When, soon afterwards, the Commonwealth Government subsidised its construction, the dock became an Allied Works Council project of highest priority, with the Queensland Main Roads Commission and the Department of Harbours and Marine Works acting as the chief constructional authorities for the Council.

A suitable site was found on the banks of the Brisbane River. It was necessary first to excavate some 350,000 cubic yards of material, the greater part of which was soft sandstone. By working in three 8-hour shifts a day, some 800 men completed the excavation within eight months. The walls of the dock, composed of a soft but impervious sandstone, required a lining of concrete only in small areas. The dock, approximately 830 feet long and 121 feet wide, could accommodate any vessel capable of negotiating the Brisbane River, which meant in effect any merchant vessel or cruiser not longer than 800 feet and with a draught not greater than 32 feet. A steam-driven 30-inch centrifugal pump assisted by two smaller (15-inch) electrically driven pumps, took six hours and a half to empty the dock of 24,000,000 gallons of water. During this operation the

[3] Only a small percentage of the 4,121 workmen (most of whom were recruited by the Allied Works Council) had had any experience of this kind of engineering construction. The speed and efficiency with which the work was completed had, therefore, considerable merit.

[4] It did possess a small, little used, graving dock.

[5] Sir John Kemp, Commissioner for Main Roads, Qld, 1920-49; Coordinator-General of Public Works, Qld, 1939, Wartime Deputy Director-General Allied Works, Qld. Of New Farm, Qld; b. Yendon, Vic, 6 Oct 1883. Died 28 Feb 1955.

dock was closed by a floating steel caisson equipped with electrically driven pumps. While it was considered to have been constructed in a remarkably short time—excavation began in August 1942 and the first vessel was docked in June 1944—it was not completed soon enough to cope with ship repairs at their peak. A total of 128 vessels (aggregating about 500,000 gross tonnage), including the two British aircraft carriers *Unicorn* and *Slinger,* merchant ships, tankers, destroyers and submarines, were docked up to 31st May 1946. Although this was technically a less difficult piece of marine engineering construction than the Captain Cook Graving Dock, it was a big one for the facilities available.

An important adjunct of the Walsh Island Shipyard was a floating dock that had been built in 1926 as the result of an agreement between the Commonwealth and New South Wales Governments. On completion, the State Government, in accordance with the agreement, took over the management of the dock, undertaking to maintain it in good order and condition and always ready for the docking and repair of ships of up to 15,000 tons displacement. It was understood that in the event of war the Minister for Defence could assume control of the dock on behalf of the Commonwealth. At Walsh Island the dock had always been operated as two separate units—the larger comprising two sections bolted together to form a dock 418 feet long, capable of accommodating a ship of 11,000 tons; the smaller unit had a lifting capacity of only 4,000 tons. It was not until the dock was moved to Dyke End that the three sections were bolted together to provide the facilities demanded by the agreement.

As soon as the New South Wales Government had decided to establish ship construction and repair facilities at Newcastle, steps were taken to assemble the floating dock as a complete unit so that it could cater for vessels up to its maximum capacity. In the meantime, the preparation of the new site, including extensive dredging operations and the construction of the heavy anchorage, was carried out, and the floating dock was moved to its new site at Carrington on Dyke End in April 1943. The linking of the three sections of the dock into one so that it could handle ships of up to 15,000 tons, in conjunction with the provision of suitable repair facilities at the dockyard, was a wise move and was an important factor in the country's effort to keep ships moving.[6]

When the war spread to the Pacific the repair of naval vessels that came limping home shattered and disabled was a task of the first importance. For a time—until Pearl Harbour had been restored and the United States had had time to build its forward and mobile bases—Sydney was very much to the fore as a base for naval operations in the Pacific. During this period the general policy was to carry out as many urgent temporary repairs as possible, leaving final repairs to be completed in ports farther away, so as to leave facilities in Sydney available for emergencies. No

[6] *The History of the Australian Shipbuilding Board,* March 1941-December 1945, compiled by the board.

attempt will be made to deal in detail with this work; a few instances only will be described in order to give some idea of its magnitude.[7]

In order to make the best use of the shipyards, to avoid delays and to ensure that due priority was given to work on vessels that could be placed rapidly in commission again, it became necessary towards the middle of 1942 (by which time the volume of work had greatly increased) to coordinate and control the repair of naval and mercantile ships.

An organisation was set up by the Australian Shipbuilding Board in charge of Engineer Commander Butcher,[8] who was lent by the Department of the Navy to act as Controller of Merchant Ship Repairs. Repair and refitting of naval vessels was organised by the Engineer Manager, Garden Island, an appointment held first by Engineer Captain Doyle[9] (until 1942) and later by Engineer Captain Hutcheson.[1] The authorities for the repair of naval and merchant vessels worked in close consultation to achieve a national distribution of effort.

One of the first naval ships to arrive in Sydney severely damaged was U.S.S. *Chicago,* whose bow had been blown off up to the waterline by a torpedo in the Solomon Islands. After surveying the damage it was decided to make temporary repairs only. The whole of the damaged portion, for a length of 50 feet and a depth of 35 feet, was cut away before any reconstruction work could begin. A new section of keel plate was fashioned, butted at one end to the existing structure and attached at the other to a new raked stem bar. Frames and floors were connected, and bulkheads and shell plates erected. This job, involving the use of over 30 tons of steel and completed in the remarkably short space of twenty-one days, was so well done that United States Naval authorities decided that it should remain as a permanent structure.

A big repair job was carried out on the American cruiser *Chester,* which had been severely damaged at the forward engine room by a torpedo. The temporary repairs effected on this vessel also earned the commendation of American naval authorities.

One of the most extensive repair jobs of all was carried out on the United States heavy cruiser *New Orleans.* About 150 feet of her bow section, from the upper deck to the water line, was missing and the remnants of the lower deck were torn, twisted and buckled. The wonder was that a ship with its hull so badly damaged was able to reach port. Repair work began with the cutting away of the remaining distorted plating, and dismantling of damaged pipe-lines and fittings. In order that it

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[7] Major repairs were carried out on the following naval ships: French sloop *Dumont d'Urville,* French light cruiser *Le Triomphant*; Dutch light cruiser *Tromp,* Dutch submarines *K 12* and *K 9*; USS *Phoenix, Chicago, Tulsa, San Juan, Chester, Portland, New Orleans, Henry T. Allen, Carine, Peter H. Burnett, LST 469, Sea Star, LST 471, Venus*; HMS *Glenearn, Illustrious, Formidable, Tumult, Venerable, Ulysses, Implacable*; HMAS's *Perth, Canberra, Swan, Australia, Stuart, Hobart, Vendetta, Arunta, Shropshire, Napier*; MV *Marina.*

[8] Engr Cdr W. G. C. Butcher, RD; RANR(S). Controller of Ship Repairs RAN 1942-46. Of Roseville, NSW; b. Claremont, WA, 16 Jul 1905.

[9] Eng Rear-Adm A. B. Doyle, CBE, BE; RAN. Third Naval Member, Aust Naval Board, 1943-48. Of Sydney; b. Scone, NSW, 5 Oct 1888.

[1] The Engineer Manager Garden Island was also the General Overseer for Sydney, and controlled the Principal Overseers at Cockatoo and Mort's Docks.

might be taken to an American base for permanent repairs, a false bow was constructed and built on to the ship. The false bow, measuring about 30 feet in length at the upper deck and 8 feet at the keel, was constructed principally from steel plate three eighths of an inch thick, and weighed approximately 70 tons. It was transferred from the building slip to the dock by the floating crane *Titan*, one of the largest of its kind.

A repair job involving the use of 85 tons of steel and 40,000 rivets was done on U.S.S. *Portland* which had been hit by a torpedo in the starboard quarter. The electro-hydraulic steering gear had been literally blown to pieces and was, in the opinion of competent ships' officers, beyond repair. The shattered mechanical equipment was completely rebuilt and motors which had been submerged in salt water for a long period and condemned as useless were reconditioned and placed in service once again.

Among the ships of the Royal Australian Navy to come in for extensive repairs was H.M.A.S. *Hobart,* which entered the Sutherland Dock on Cockatoo Island with a large gaping hole in her hull and a wrecked after gun turret. The after end of the ship was found to be twisted out of line. For the purpose of correcting this distortion a large wooden cradle with fixed and sliding ways so that it resembled a launching cradle, was constructed before cutting away the damaged stem section. The straightening operation, achieved with hydraulic jacks, was made in four moves at intervals of two hours and a half. The twisted and cracked forward section of the stern casting was cut out, straightened under a hydraulic press, and after heat treatment was welded back in place. The remarkable feat of straightening this large and intricate casting in a couple of weeks saved many months that would have been required to make a new casting.

Another result of the torpedo hit was serious damage to the main shafting: several lengths needed straightening and an intermediate and propeller shaft had to be renewed. The machining of these two shafts made history at Cockatoo Docks: it was the first occasion that such great lengths of shaft (one 45 feet long, the other 70 feet long) had been trepanned. In trepanning, a core three inches and three-quarters in diameter was removed throughout the full length of each shaft in one operation. While all these repairs were being effected *Hobart* underwent many alterations, bringing her up to date in radar and other equipment.

Off Leyte in October 1944 H.M.A.S. *Australia* suffered severe damage, intensified by a Japanese suicide plane crashing into the superstructures and funnels. Extensive repairs to the *Australia* were made in the later part of January 1945.

One of the last major repairs to be made in naval vessels was carried out on H.M.S. *Formidable* in the Captain Cook Graving Dock. A Japanese pilot had caused great damage by crashing his aircraft on to the flight deck, opening up the deck and buckling the special 3-inch thick armour plate. To repair the deck was a job of considerable magnitude. Two armour plates, each weighing 14 tons, were removed and straightened under a hydraulic pier; a third, damaged beyond repair, was replaced by plates of lesser thickness but of similar special quality steel. Drilling the

rivet holes in the extremely tough steel to match the newly constructed heavy steel girder beneath was a long and exacting job.

The Japanese threat to North-Eastern Australia made it necessary to consider the establishment of an alternative naval base to Garden Island. With this in mind the Commonwealth Government negotiated the purchase of Williamstown Dockyard from the Melbourne Harbour Trust Commissioner. This dockyard, where much work had already been carried out for the Commonwealth, was completely reorganised in 1941 by the installation of additional berths, workshops and cranes for the purpose of building "A" class merchant ships. The two ships already begun were completed under the auspices of the navy. Thereafter the main activities of the dockyard were directed to the refitting and repairing of naval vessels.

For sheer volume of work few activities exceeded those of the Garden Island and Williamstown Naval Bases, where large numbers of vessels of many classes from the Australian, United States, Dutch and Free French Navies were refitted. The installation of the latest types of radar, asdic, fire control, degaussing and other complex technical equipment formed a large part of the refitting, the extent of which grew as the war progressed and reached a crescendo with the arrival in Australia of the British Pacific Fleet. Work on ships of the British Fleet, which was spread over the major dockyards, was the industry's last great wartime effort.

While the work of repairing naval vessels so that they might take their place again in the battle areas was one of the most valuable contributions of Australian shipyards, a scarcely less important contribution was the repair and maintenance of a far larger number of merchant vessels. The pressure of work on Australian shipyards from this source was greater than that caused by the war in the Pacific alone. For example the occupation of Europe by the enemy meant that those ships able to escape had to be repaired in other parts of the world. To activities of this kind Australia contributed her share. The majority of the 12,160 Australian and Allied merchantmen (representing 53,079,182 tons) that underwent repair or maintenance in Australian harbours during the war were handled at wharves while cargo operations were in progress; but 1,869 ships (representing 6,464,211 tons) were dry docked.[2] A large number of these were so seriously damaged that they required long periods in dry dock before under-water repairs could be carried out. "At this time," Hutcheson recalls, "it was possible to take a motor boat up Sydney Harbour and actually put its bow inside several torpedoed ships, and this was one of our favourite ways of impressing on distinguished visitors, especially those from U.S.A. who were determining what to allow us under Lend-Lease, how urgent some of our requirements were."[3]

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[2] These figures do not indicate the number of individual ships repaired; some came in more than once.

[3] Engr Capt G. I. D. Hutcheson, RAN. "War-time and Post War Shipbuilding"—Review of Sydney's Effort. *United Service*, Vol. 2 (1949), p. 500.

The building and repair of ships on the scale undertaken during the war was, as with practically every other wartime undertaking, hampered by the lack of skilled manpower. This was especially true of electricians who installed radar, fire-control and communication equipment, and also of boiler-makers who did the structural steel work on ships. While almost all other unions accepted the principle of dilution of labour the Balmain Branch of the Boilermakers' Union—to which most of the waterside boiler-makers in Sydney belonged—steadily refused to do so.

Liberty ships and many Standard Oil tankers were damaged by collision, stranding or enemy action. These vessels, which were of entirely welded construction, were at first difficult to repair in Australia owing to the lack of experience in welded-ship construction, but welding techniques at the State Dockyard were quickly developed to a point where these ships could be repaired to the satisfaction of the inspectors of the American War Shipping Administration.

As the war developed, small craft played an increasingly important part in the Mediterranean, in Western Europe and in the Pacific. Soon after American forces arrived in Australia and began to use it as a base for operations against Japan, their transport authorities began to ask the Australian Government for assistance in providing small craft. As a first step the Government commandeered all privately-owned small craft, but of course these met only a small fraction of the needs and were not always of the types required. In November 1942 when the Americans began placing orders, among the first items asked for were 9 barges of a type that could be towed behind Liberty ships. To meet this request the Australian Shipbuilding Board, which was responsible for supplying the American requirements, designed a dumb lighter capable of carrying a load of 2,000 tons. It was not long before changes in design were asked for—first that lighters should be powered so that they could cruise among the Pacific Islands. This had no sooner been done than it was announced that lighters capable of operating entirely under their own power were required, and in large numbers (150). To meet this demand the Australian Shipbuilding Board then designed the 120-foot ocean-going lighter, which proved to be the most important of the small craft. At first the changes in design that were constantly being called for greatly increased the difficulties of the engineers responsible for production, but it was not long before American transport authorities found their feet. Design of the 70-odd types of small craft called for by the Americans was one of the board's biggest problems, but with the aid of the Department of the Navy it was quickly surmounted. By the middle of 1943 small craft were being produced in considerable but by no means sufficient numbers.

In August of that year—about nine months after the first American orders—the Australian Army began to place its orders for small craft. A difficult situation now arose. The American authorities, finding that small craft from the United States were not arriving in the numbers anticipated, became more insistent in their demands on Australian in-

dustry. At the same time the Australian Army began to complain that its requirements were not being met quickly enough. The inescapable conclusion was that the Australian Shipbuilding Board had far more work than it could cope with: it was having the greatest difficulty in finding both manpower and materials. American complaints forced the Government to take some action. The War Cabinet asked the Director-General of Munitions, Mr Essington Lewis, to assume direct control of small craft production in Australia and to make his department responsible for the supply of vessels up to and including the 120-foot steel ocean-going cargo vessel then on order for the United States Army. This he agreed to do and in October 1943 appointed Mr Merrett, his personal technical adviser, Director of Small Craft Construction, with Mr Bromley as Controller. At this time it was estimated that the cost of the whole program would be about £23,000,000, of which small craft costing £1,076,872 had already been delivered to the Services or were in the course of construction. Of the total, approximately £18,000,000 was for the United States Army, which was then receiving first priority, £5,000,000 for the Australian Army, £270,000 for the Australian Navy, and £450,000 for the Australian Air Force.

On 23rd October, thirty-one members of the staff of the Australian Shipbuilding Board reported for duty at the temporary offices hurriedly provided for the new directorate by the Sydney Board of Area Management. The team included eleven technical men experienced in shipbuilding and in marine diesel engines. They were soon joined by officers of the Factory Equipment Section who had been working under Merrett since the early days of the war, and also by members of the design staff of the Armoured Fighting Vehicles Directorate then in process of being disbanded.

Fortunately for the staff of the new directorate, most of whose members were unfamiliar with marine engineering, a great deal of spade work had already been done by the Shipbuilding Board and the Department of the Navy. The former had already organised a vast program of small craft construction with contractors scattered along the whole of the inhabited Australian coast; contractors whose facilities, strength, failings and problems had been laboriously recorded in the mountainous files which accompanied the staff from the Australian Shipbuilding Board. The new directorate's task was to galvanise the industry into action to the limit of its capacity. Behind it was the Munitions Department now fully geared for production and ready to help.

By this time the number of types of vessel called for had reached 110 and included landing craft, lifeboats, refrigeration barges and pontoons. There was the customary shortage of skilled labour. To meet it retired boat builders and shipwrights were recalled from their seclusion, and together with those already active they began teaching cabinet makers, joiners and carpenters how to use the broad axe and the adze, how to shape and bend timber and to make and fasten joints. Almost every harbour in the Commonwealth took part in the small craft program.

Problems of wood technology, such as finding substitutes for the oak, fir and teak called for in British specifications, and inspection of all timbers supplied for small craft construction, were the concern of the N.S.W. Forestry Commission's Division of Wood Technology, and of the C.S.I.R. Division of Forest Products in Victoria. Inspection of timber for small craft, while not nearly so critical as for aircraft, was an important task.

Some of the late designs were carried out by the navy, army and air force, and others by the staff of the directorate. All designs had to be approved as seaworthy by the Design Panel of the Small Marine Craft Sub-Committee, presided over by the Third Naval Member, Engineer Rear-Admiral Doyle.

The story of small craft production was remarkable not so much for the conquest of technical difficulties, as for the size of the effort, its organisation and its ramifications into many other industries. More than 100 contractors, in all States, built hulls and fitted out the craft. In addition 764 contractors were engaged directly in the production of component parts. The Australian Shipbuilding Board, and later the Directorate of Small Craft, acted as coordinating contractor for the supply of all fittings and parts to craft outfitters, while the Boards of Area Management in the different States, aware of the extent of industrial capacity available and trained in the procurement of myriads of component parts, gave invaluable help. Manufacturers of motor-car bodies, builders and contractors, furniture and sporting goods manufacturers, engineering companies, and heavy industry all took part in the construction program. An interesting example of the adaptability of industry was provided by Slazengers Ltd, a firm with no experience whatever of shipbuilding. By applying the technique of laminating wood that they were accustomed to use in making tennis racquets Slazengers were able to build the hulls for hundreds of motor dories.

As with larger craft, one of the more serious problems was the supply of engines. Among the engines selected as being most suitable was the General Motors diesel-powered Gray Marine unit, which weight-for-weight was as powerful as any of its kind; General Motors-Holden's were given the contract to make 500.[4] The castings of the cylinder head and cylinder block presented a major problem since no foundry in the country was capable of making them at the rate and to the accuracy required without considerable additional equipment. These castings were, for their size, probably the most complicated made in Australia up to that time. Another tricky technical operation required in the making of this engine was the boring, in accurately predetermined directions, of seven tiny holes each 0.0062 inch in diameter in the spray tip of the injector. In spite of these and other difficulties the engines were successfully built and when fitted into marine craft sent to the battle areas they gave excellent performance. An equally notable achievement was the building of some hundreds of

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General Motors-Holden's were entrusted with the production of no less than 7 different types of engine for the Services: two of them made for the first time in Australia were the Gipsy aero-engine and the engine for the 18-in naval torpedo.

heavy-duty diesel engines (Ruston Hornsby 7VCMB 200 h.p. Marine Propulsion Diesel Engines) by the Ordnance Factory at Maribyrnong, and by Charles Ruwolt of Melbourne,[5] both in a remarkably short time. The cylinder head of the Ruston Hornsby Diesel was not so complex a casting as that of the Gray Marine unit, but the manufacture of crankshaft and atomiser were just as, if not more, difficult.

Fast supply boats, 38 feet long and capable of a speed of 30 knots, were designed and built by Lars Halvorsen Sons Pty Ltd. They were extensively used to carry patients and medical stores. Steel landing craft built to American design also played a major part in the island campaigns. Perhaps the most versatile of all the units were the steel pontoons designed by the Australian Shipbuilding Board to American requirements. They were essentially steel boxes, 6 feet wide, 7 feet long and 5 feet high, so made that they could be strung together to make a long pontoon from the shore, or even a floating dock for small craft.

Unique among small craft was the "Crusader", a 1,500 ton box-like steel craft designed by Major-General Steele[6] for the purpose of transporting large numbers of landing barges or tanks. The "Crusader", the first large all-welded steel vessel to be built in Australia, was launched at Williamstown Dockyard in August 1945. Its unorthodox design did not greatly impress marine engineers.

Australia's contribution to the invasion fleet of the Pacific was a notable one, comprising as it did 33,643 small craft of 162 different kinds, costing approximately £16,000,000. Most of them were built within about two years.[7]

Mainly as a result of the impetus given by war, Sydney became the largest and best-equipped port for ship maintenance in the Southern Hemisphere. By the end of the war the shipbuilding industry had been placed on a firm technical basis but had yet to prove that it could survive competition from overseas under peacetime conditions. Its excellent record during the war was no guarantee of survival. Conditions necessary for the establishment of a sound shipping industry in Australia were quite different from those operating in the United Kingdom. There the industry grew up in the absence of outside competition and developed a high degree of specialisation, with consequent efficiency and economy in costs of production. Some firms on the Clyde built only cargo vessels of a more or less simple design; others specialised in passenger vessels, or oil tankers,

[5] In singling out different contractors an arbitrary selection is often made. Complete lists of names of sub-contractors and others concerned would, over the whole shipbuilding program, probably involve practically every engineering establishment of any size in the C'wealth.

[6] Maj-Gen Sir Clive Steele, KBE, DSO, MC, VD; BCE. (Served 1st AIF.) CRE 6 Div 1939-40; CE I Corps 1940-42; E-in-C LHQ 1942-45. Consulting engineer; of Melbourne; b. Canterbury, Vic, 30 Sep 1892. Died 5 Aug 1955.

[7] They included:
584 powered steel craft including landing craft
1,158 unpowered steel craft
1,090 powered wooden craft
2,144 unpowered wooden craft
14,389 N.L. pontoons
8,276 lifeboats, dinghies and miscellaneous craft.

or tugs and dredges. The design of such vessels was quite a complex matter and specialists in one field were likely to be of little use in another. Every old-established shipbuilding firm in the United Kingdom had a great fund of experience to draw upon and a large market close at hand.

Because of relatively small requirements there was little prospect of Australian shipyards being able to specialise in this manner. To survive they would have had to cater for a greater variety in size and type of vessel than their competitors in major shipbuilding centres. An analysis of probable Australian shipping needs in the post-war period[8] indicated that they would in all probability provide sufficient basis for a permanent industry, since Australia was dependent to an unusual degree on coastal shipping for the transport of basic raw materials.[9]

Shipbuilding continued in all the more important shipyards after the war, principally under the aegis of the Australian Shipbuilding Board. With the exception of tugs, dredges and ferries, the only extensive shipbuilding carried on independently of the board was that of B.H.P. at Whyalla. This company continued to build ships to serve its own industries, and Whyalla became the leading centre in the Commonwealth for the building of merchant ships. Post-war naval construction, concerned chiefly with *Daring* class destroyers, was continued at Cockatoo Docks and at Williamstown, but experience made it clear once again that the volume of peacetime naval construction was inadequate to sustain a sizable industry.[1]

[8] D. Lyon McLarty, *Shipbuilding in Australia.* Published by the Inst of Industrial Management (1945).

[9] Later figures given by *The Structure and Capacity of Australian Manufacturing Industry*, published by the Division of Industrial Development, Dept of National Development (1952), p. 250. Australian coastal shipping industry requires 36,000 deadweight tons a year for economic operation. Present rate of production (1952) 25,000 deadweight tons. Maximum capacity of shipbuilding yards best placed to contribute was 90,000 tons.

[1] In writing this chapter I had the benefit of helpful discussions with Eng Capt G. I. D. Hutcheson, Mr H. P. Weymouth, Mr M. W. Mehaffey and Mr H. J. Bromley.

CHAPTER 21

COMMUNICATIONS

IF for no other reason than its volume, the radio industry's part in arming the nation would deserve a prominent place in this history. Estimates of the amount of money spent on the manufacture of radio and signal supplies varied with the basis upon which they were made. One estimate, made on the broadest possible basis, placed the sum at £40,000,000.[1] Such an achievement would have been impossible had it not been for efficient commercial organisations built up between the wars to meet peacetime needs. Without this solid foundation the radio industry could not, in the time, have developed the facilities needed to handle the work it was called on to do. This background was particularly important because the radio and electrical industry, alone among the major wartime industries, had no counterpart in the government factories to which it could turn for advice and from which it could recruit trained staff.

The early history of the radio industry in Australia was intimately associated with Amalgamated Wireless (Australasia) Ltd (A.W.A.) and with Mr Fisk,[2] who for many years directed its activities. From its inception in 1913 the company set out to build up a self-sufficient organisation to supply Australia's needs for radio-communication equipment. For the first few years of its existence A.W.A. was occupied mainly in fitting ships and shore stations with imported equipment for wireless telegraphy; one of its contracts during the 1914-18 war was to equip vessels that had been built in Japan for the British Merchant Fleet. Very shortly after that war it began to design and build its own equipment for installation in ships.

Direct radio-telegraphic communication between Britain and Australia was first achieved on an experimental basis in 1918. Six years later the first radio-telephonic link was forged.[3] The corresponding public services to the United Kingdom and North America were instituted in 1927 and 1930 respectively. Just before the inauguration of the Beam Wireless telegraphic system A.W.A. raised its capital to £1,000,000 and agreed to an arrangement under which the Commonwealth Government acquired a little more than half the shares. The idea behind this arrangement was that in the event of an emergency, such as war, the government would be in a position to control oversea communication. The main receiving and transmitting station for both telegraphic and telephonic services was located at Rockbank, Victoria.

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[1] "The value of (the Radio) Industry's Achievement", an article which appeared in a special issue of the *Radio and Electrical Retailer*, Vol. 23, No. 16 (1946), entitled "Australian Telecommunications at War".

[2] Sir Ernest Fisk. Managing Director A.W.A. 1917, Chairman of Board 1932-44; Director Economic Coordination 1939-41. Chartered engineer and electrical engineer; of Sydney; b. Sunbury-on-Thames, Eng, 8 Aug 1886.

[3] In 1918 Marconi's longwave (20,000 metres) station at Carnarvon (Wales) transmitted the first direct wireless telegraphic message from Britain to Australia. It was received at an experimental station conducted by Fisk in the Sydney suburb of Wahroonga. Fisk later transferred his laboratory to Vaucluse where in 1924 he received the first human voice transmission from Marconi's station at Poldhu (England).

The experience in 1914-18 was that war greatly accelerated the growth of communications: the number of cable messages handled in Australia grew from 10,000,000 words a year in 1914 to 19,000,000 in 1918. With this experience in mind, A.W.A. on the outbreak of the second world war prepared to cope with a similar increase in the traffic load by increasing the carrying capacity of its beam circuits. In the event the load increased from 30,000,000 words in 1939 (radio telegraphic and radio telephonic) to 90,000,000 a year by the end of the war.[4]

The introduction of radio broadcasting in 1922 gave rise to a new section of the radio industry, namely the manufacture of broadcast receivers. Until the imposition of a protective tariff in 1930 the industry depended to a large extent on imports for the component parts and was therefore limited to the assembly of receivers. It was one of the very few industries that flourished in the economic depression, for radio was one of the cheapest forms of entertainment. Under these favourable circumstances A.W.A. established in 1933 the first modern receiving valve factory[5] in Australia. Two years later Philips Lamps (Australasia) Pty Ltd[6] built a factory in which receiving valves were assembled from imported components.

About this time the Commonwealth Government decided to modernise the national broadcasting network and placed orders with A.W.A. for 7-kilowatt and 10-kilowatt radio-broadcast transmitters. Standard Telephones and Cables Pty Ltd (S.T.C.) built a 60-kilowatt transmitter for the New Zealand Government. Many commercial stations which had previously built their own transmitters began to see the advantage of buying factory-made equipment, and the resulting demand did much to place this section of the industry on its feet. The manufacture of transmitting valves was begun by the Amalgamated Wireless Valve Company in 1937 and by S.T.C. in 1939. These developments were important for defence: the transmitter section of the industry—its most difficult and exacting branch —then employed the greater proportion of Australia's electronic engineers (who numbered not more than 100) and had already produced equipment of high quality designed for long life under exacting conditions. It was therefore readily adaptable to designing and manufacturing equipment for the Services. On the other hand the standards of engineering and quality of production of the radio receiver industry were generally below the requirements of the Services, and at first there seemed little prospect that this part of the industry would contribute much to munitions. However, after some initial setbacks it rose remarkably well to the occasion.

In the years before the war of 1939-45 the Signals Corps of the Australian Army was trained exclusively on British equipment. A few copies

[4] These figures refer to paid messages and do not include the thousands of free messages sent from children evacuated from England, Christmas messages from the troops, and messages from released prisoners of war.

[5] The Amalgamated Wireless Valve Co Pty Ltd.

[6] The company's name was changed in 1943 to Philips Electrical Industries of Australia Pty Ltd, and in 1952 to Philips Electrical Industries Pty Ltd.

of British Army field wireless sets had been made by the Postmaster-General's Department, but these made no significant contribution to the army's requirements. The main field wireless set in use at the time was a British set using low-tension and high-tension dry batteries. Late in 1938 army authorities decided to modernise the communications equipment at their disposal. As a first step they called tenders for a vibrator type of power supply to replace the dry batteries of the British set. S.T.C. was awarded a contract for the design and production of this equipment. The army then decided to introduce two new field wireless sets, contracts for which were given to S.T.C. and A.W.A. One of these sets, type 109 made by S.T.C., was used throughout the war and was the first field radio to be taken into battle by the Second A.I.F. At a critical stage during the siege of Tobruk it was the only means the British forces had of maintaining communication with the outside world.

As might be expected from the close relationship it had always maintained with the Royal Navy, the Australian Navy adopted British equipment for shipboard use. It was only towards the end of the war that some of the smaller naval vessels built in Australia were equipped with locally-made radio and radar sets. The main naval shore stations built at Canberra and Darwin just before the war were equipped solely with equipment made and designed in Australia.

The R.A.A.F. at first relied entirely on oversea equipment for its aircraft, which was natural enough since imported aircraft arrived with their communication equipment already installed. Its ground stations, however, were equipped from Australian sources. In 1938 the air force ordered a considerable number of 10-channel 1-kilowatt high-frequency transmitters to equip its ground stations. These were an ordinary commercial transmitter then being produced by S.T.C., and were used by the R.A.A.F. to enable a communication network to be established while specifications were being prepared for Service equipment. The foresight shown by the navy and the air force in equipping their shore and ground stations proved invaluable after Japan entered the war, because these stations were able to take over the whole of the traffic for the South-West Pacific Area previously handled by Singapore.

When Australia began to manufacture aircraft she was faced with the necessity of providing them with communication equipment which, being by then unprocurable overseas, had also to be made locally. The R.A.A.F. was well prepared for this contingency. Early in 1939 its Signals Staff had prepared functional specifications[7] for four main items of Service radio equipment: a radio compass, a communications receiver, a communications transmitter, and a complete aircraft transmitting and receiving unit. The task of designing equipment to meet specifications for the last of these items was given to A.W.A. Development of a suitable receiver-transmitter for operation on medium to short waves and for use in aircraft, involved the construction of a low-temperature, low-pressure chamber to simulate

[7] The user, or functional, specification merely stated the performance expected of the equipment; it did not give instructions how this performance was to be achieved.

the conditions that the equipment would be exposed to at high altitudes. This was the first instance of the use in Australia of a "high altitude" chamber for testing radio equipment. The set finally evolved, known as AT5/AR8, was highly successful—so much so that it was later adapted for many other purposes.

For the first two years of the war each Service looked after its own needs as best it could, seeking out manufacturers to make and develop prototypes; when these had proved satisfactory the Contracts Board was asked to arrange for mass production. There were no facilities for standardising communications equipment, and no organisation with the status, for instance, of the Munitions Supply Laboratories, to coordinate and control activities. The high priority accorded to radar made it impossible to secure an adequate flow of supplies for communications equipment, and the resources of many contracting firms proved inadequate for the manufacture of new types of highly specialised equipment. After the entry of Japan into the war these haphazard and inefficient methods could not be allowed to continue.

In January 1942 a small section was created in the Department of Munitions for the purpose of organising the commercial manufacture of radar and signal equipment, and placed under the leadership of Lieut-Colonel Jones. Within six months the need for a more comprehensive organisation had become so pressing that the section was expanded and transformed into the separate Directorate of Radio and Signals Supplies, responsible for directing the production of all the radio and radar equipment used by the Australian Services, and of a good deal of that used by New Zealand and American Forces in the South-West Pacific Area. It was the directorate's task to hold the balance between competing claims, assist in the development of new sources of supply and new techniques, select contractors, arrange for import of supplies where this was unavoidable, and generally to promote the smooth flow of equipment to the Services.

The sudden call for equipment, so much of which was new to manufacturers, put a severe strain on much of the industry since it had neither the range of tools and facilities nor the reserves of skilled labour that were available in more highly industrialised countries. Many skilled men of the radio industry had already been taken into the technical branches of the Services; others had been allowed to enlist in non-specialist branches. Evidence was growing daily that the industry was far more dependent on oversea sources for material supplies than had been generally supposed. It took the broadcast-receiver manufacturers some time to adjust themselves to the new outlook needed to manufacture equipment of the standard demanded by the Services. A high level of performance in reception and transmission was not the only requirement; Service equipment had to be robust enough to withstand conditions of climate and handling far more severe than those to which any domestic receiving set was ever subjected. The urgent demands for delivery meant that manufacturers

tended to strive for a large output rather than to satisfy fully the exacting requirements of the users of the equipment.

The Directorate of Radio and Signal Supplies was organised into a number of divisions, which could be grouped under two main headings: (*a*) servicing divisions—administrative, engineering, materials and controls (civilian radio); (*b*) production divisions—radar, radio, and signalling equipment other than radio.

The broad general functions of all three production divisions of the D.R.S.S. were very similar: each was concerned with supervising the production throughout Australia of its own particular class of equipment at a general administrative level. That is to say, they selected contractors for manufacturing any materials required and assisted State Boards of Area Management in arranging for the production of complete equipments. It was each division's responsibility to obtain from overseas any special materials required and to issue these to contractors through the Munitions Department. As a check on the general progress being made, the divisions made a monthly survey of production to the Assembled Services Stores Committee. Since radar has already been dealt with in a separate chapter, little will be said about it here. The Radio Division was concerned with transmitters (ground stations and mobile stations), communication receivers, smaller walkie-talkie equipment and mine detectors. The Signal Division on the other hand covered all signalling equipment except radar and radio: telephones, pole-line hardware and visual signalling equipment. Some equipment was built to designs supplied by Britain and the United States, but much of it was of Australian design.

The function of the Engineering Division, under Dr Pulley, was essentially to help manufacturers translate prototype equipment from the laboratory to mass production. In the first instance the scope of its activity was limited to radar equipment, but as the usefulness of the division became apparent it came to be consulted on problems concerning communication equipment, most of which arose from the fact that when the Services modified oversea designs they often failed to define their requirements precisely enough.[8]

No provision had been made in the organisation of the Munitions Supply Laboratories for experimental work on the multitudinous problems that arose in connection with the development of telecommunications and radar. For radar, the Radiophysics Laboratory had been specially built in the early days of the war; for communications, the Research Laboratories of the Postmaster-General's Department were used as far as it was possible. In addition to its primary function of conducting the postal service, this department maintained internal civil communications throughout Australia and provided technical facilities for the Australian Broadcasting Commission. The technical resources and organisation of the P.M.G's Department were used right from the beginning of the war when it was made one of the major coordinating contractors for the supply of tele-

[8] "History of the Directorate of Radio and Signals Supplies", p. 97.

communication equipment to the armed forces. After the Directorate of Radio and Signal Supplies had been set up the department continued as a research and development agency.

Over and above the shortage of skilled men which was common to all industries, two factors tended to limit the rate of expansion of the radio industry in the early years of the war: scarcity of testing equipment and shortage of raw materials and certain important components such as valves. Since the scarcity of testing equipment was world-wide there was no alternative but to manufacture it locally. Indicating instruments—ammeters and voltmeters—bridges, oscilloscopes, field-intensity measuring sets, signal generators, "A" meters and "Q" meters, figured prominently among measuring instruments whose local manufacture was the result of wartime deficiencies.

Before the manufacture of electrical indicating instruments could be properly established considerable improvements had to be made to existing methods of making such important components as pivots and springs. No attempt had ever been made to produce synthetic sapphire on a commercial scale in Australia, and consequently there was a shortage of instrument jewels, which was only partly overcome by the use of glass bearings and other inferior substitutes. The National Standards Laboratory then designed an improved plant for making pivots, while the Metallurgy Section of the Munitions Supply Laboratories helped by developing successful techniques for producing and testing the specially hard steels used in making them. A plant for making pivots was built by the firm of J. A. Bourke, Sydney, and allotted to the Australian Jewel and Pivot Company. Improvements to existing local methods for making small springs for instruments were made by the Munitions Supply Laboratories, which designed and constructed a special plant for the purpose. The plant was allotted to the Synchrotac Instrument Co Pty Ltd, Melbourne. The laboratories not only designed and constructed the plant, but supplied the special steels and did much to ensure that springs were made from uniform strip that had acquired, through proper heat treatment, all the elastic properties required of the finished product. Unfortunately this work on instrument pivots and springs was completed too late for the wartime radio industry to reap its full benefits. The industry was compelled to make do with pivots and springs of lesser quality eked out by imports of better quality materials.

An example of the work of smaller firms in undertaking almost overnight the manufacture of meters and instruments previously imported, was that done by A. J. Williams Electrical Instruments, Melbourne. This firm concentrated largely on precision instruments of working standard quality, but it also produced a large range of other types as well. In undertaking the manufacture of these instruments many new problems were tackled with great success, and jobs such as making meter pivots with a spherical point 5/10,000 of an inch in radius, and producing drawn seamless aluminium tubing with an external diameter of 0.028 of an inch and walls 0.001 of an inch thick, became workshop routine. Another notable

achievement in the manufacture of high-grade scientific instruments was the pH meter made by G. H. Sample and Son (Vane Instruments) of Sydney, which found much use in chemical laboratories and the food industry. Thermocouples made by Vane Instruments for use in radio equipment proved to be highly satisfactory.

Large numbers of instruments for testing communications equipment were made by the major firms of the radio industry: A.W.A., Radio Corporation, Philips, Gramophone Company, and Airzone. The first-named company built a separate branch factory in which it made a very wide range of instruments. "Specialist" firms also contributed: Warburton Franki Ltd and Master Instruments Pty Ltd (both of Sydney) made meters for radar equipment; the Radio Equipment Co Pty Ltd and Transmissions Products Pty Ltd made a wide range of workshop testing instruments; and A. G. Healing Ltd made "Q" meters. It is not practicable to list every firm that was concerned. To all of them the facilities of the Directorate of Radio and Signal Supplies were available; many of them benefited considerably from its help.

An illustration of the shifts to which radio engineers were at first put is provided by the story of the manufacture of coaxial cable used to conduct ultra-high-frequency currents. Polystyrene, the only insulating material then known with the electrical characteristics required for this cable, was not made in Australia and could not be imported. The Directorate of Radio and Signal Supplies therefore impressed all stocks held in the Commonwealth, most of which came from makers of umbrella handles. Much of it was coloured, but all except the red and grey (the latter contained aluminium powder) was usable. Millions of beads were moulded from the polystyrene, threaded on to copper wire and then braided over by bootlace machines (by Braided Products Ltd of Sydney). They were covered first with copper wire, then with cotton, and then lacquered; finally a thin coating of polyvinyl chloride was extruded over the cotton. Without this makeshift coaxial cable Australia would have been unable to make radar equipment.

The manufacture of several types of coaxial cable involving the fabrication of imported synthetic insulating materials such as polystyrene, and later polythene, was successfully undertaken by the International Radio Co Pty Ltd of Sydney, and Moulded Products (A/asia) Ltd of Richmond, Victoria. The flexibility of polythene and the ease with which it could be extruded directly on to a wire in a continuous seamless covering made it superior to polystyrene. Polyvinyl chloride, the manufacture of which was begun by I.C.I.A.N.Z. towards the end of the war, proved to be a valuable material for resisting the action of tropical humidity and was extensively used as an insulating covering for many different kinds of cable.

A notable development in insulating materials was the manufacture of laminated sheet paper impregnated with phenol-formaldehyde resins—a material essential to practically all telecommunication equipment. It was notable in the sense that the basic material phenol formaldehyde was

made locally (by Monsanto in Victoria) for the first time. Moulded Products was signally successful in making the laminated insulation to the high standards required of Service equipment.

The Engineering Division of the directorate spent much of its energy assisting the development of ceramics and synthetic resins, and of moulding powders suitably impregnated to withstand high humidities of tropical climates. Practically all ceramic components, such as switch parts, coil formers, small bushings and condensers, were made locally, but owing to the variability in the quality of raw materials and the small demand for high grade porcelain in Australia it was some time before a quality sufficiently high for precision communication equipment and radar equipment was attained. Nilcrom Porcelains Pty Ltd of Northcote, Victoria, made a most useful contribution to the wartime radio industry by producing close-grained, non-hygroscopic insulators and formers with dimensions accurate to within one or two thousandths of an inch. The same company, together with Ferro Enamels Ltd, New South Wales, and the Ducon Condenser Co Ltd, and helped very largely by their oversea associates, developed the manufacture of steatite insulators for use in high-frequency radio communication equipment to the point where Australia became more or less self-sufficient in this field. The widespread demand for steatite (a synthetic magnesium silicate) for Service equipment stimulated local manufacturers to undertake its production, and in the latter years of the war fairly substantial improvements in quality were brought about.

Up to the end of 1943 no serious attempts had been made to devise tests, other than a simple visual one, to find out whether Australian mica was suitable for making capacitors or not. Special tests devised in the laboratories of the State Electricity Commission of Victoria revealed that visual tests alone were a most unreliable guide and led to the rejection of some suitable mica and the acceptance of some unsuitable mica. Test equipment for detecting metallic inclusions and other defects in mica was therefore obtained from the United States and installed in both Sydney and Melbourne. The Mica and Insulating Supplies Co Pty Ltd, Melbourne, played a leading part in fabricating this type of material, and achieved some success in supplying it for high-powered machinery.

In cutting thin wafers from quartz crystals for use as piezoelectric oscillators it was essential that the direction of the cut should be accurately fixed in relation to the crystal axes. Before the war, owing to the smallness of the Australian requirements, this work was carried out by methods which were rather slow. After the positions of the crystal axes had been fixed approximately by optical methods or, where the crystal was water-worn, by etch-pattern methods, a wafer was cut and its electrical performance was tested. From its behaviour under this test a correction could be applied which would enable subsequent wafers to be cut with the desired degree of accuracy. War so increased the demand for crystal oscillators that new methods had to be adopted in order to speed up their production. One innovation was to employ the technique of X-ray diffraction in making the final adjustment of the direction of cutting instead of the trial-

and-error method previously used. This method was employed by both A.W.A. and by Electronic Industries Ltd, Melbourne, who between them were able to increase the output of quartz oscillators from a few hundred before the war to many thousands a year by 1944. The oscillators, large numbers of which were made from quartz crystals mined at Glen Innes, New South Wales, were used almost exclusively for the accurate control of frequencies used in radiocommunication.

One of the problems the Radio Division of the Directorate of Radio and Signal Supplies had to attend to was the supply of valves, which were essential for all types of telecommunication and radar equipment.[1] With the increase in demand that followed the entry of Japan into the war, Australia was faced with a serious shortage of valves of all kinds, not so much because industry lacked the skill to make them, as because of a shortage of valve components and of the materials used in making the components. Before the war three companies which between them made about 80 per cent of all the valves used in broadcast receiving sets and transmitters—the Amalgamated Wireless Valve Co, Philips Radio Works, and Standard Telephones and Cables—depended almost entirely on oversea sources of supply for tungsten wire and light-gauge nickel and molybdenum sheet. When Holland was overrun by the German Army, Philips' Australian company was cut off from its main source of valve parts, and stocks fell to a very low level. As British firms were not in a position to help, Philips turned to the United States, but by the end of 1941, when stocks were almost exhausted, orders placed there had still not been delivered. Standard Telephones and Cables were little better off. The plight of these two firms was partly offset by the fact that supplies to the other major manufacturer, Amalgamated Wireless, whose annual output in pre-war years had amounted to about 900,000 valves, were ensured for some time to come as a result of the firm's normal practice of stockpiling of materials and prefabricated component parts. These stocks, together with additional supplies obtained from their established oversea commercial sources, enabled the company to meet Service requirements until late in 1943 when "Lend-Lease" materials became available. However, it was at the time by no means certain that these supplies would last out, and the D.R.S.S. took over the control of valve manufacture with the avowed object of making Australia self-sufficient in valve materials. This became the directorate's largest project.

In 1943 Jones set up two advisory committees to assist the directorate: the Valve Production Advisory Panel to advise on the standardisation of valve manufacture so that the large number of different types of valve now needed could be produced with greatest economy of manpower and materials; and the Valve Materials Committee,[2] to give technical assistance to valve manufacturers and advice about critical materials. This committee directed development work, carried out, for the greater part, in a

[1] The transistor had not been developed at this period.

[2] Members: S. O. Jones, Chairman; Profs T. H. Laby, E. J. Hartung and J. N. Greenwood, and Drs L. H. Martin and I. W. Wark.

laboratory attached to the Metallurgy Department of the University of Melbourne. A team of metallurgists, of whom Professor J. N. Greenwood was the leader, set about the problem of making fine tungsten wire, an important component of radio valves which was then in short supply all over the world.

The production of the pure powdered metal from Tasmanian (Storey's Creek) wolframite, the most suitable ore readily available, offered no difficulty. The main problem that had to be solved was to fabricate wire from a powdered metal whose melting point was higher than that of any other metal. Very little work had previously been done on powder metallurgy in Australia and it was some time before the operations of sintering, swaging and drawing tungsten into wire were successfully accomplished. But with machinery provided by the British Ministry of Supply, and with the help of technical details and drawings brought by Dr L. H. Martin from the Westinghouse Company in the United States, and by considerable and ingenious improvisation of equipment, Greenwood and his team ultimately succeeded in drawing tungsten wire (in carbide dies) to 0.005 inch in diameter. Finer wires still were later drawn with diamond dies. The coarser tungsten wire (actually rod 2.4 millimetres in diameter) found use in "micropup" radar valves; some of the finer wire was used for sealing through glass and as supports in valves, but all the pure and thoriated wire required for valve filaments had to be imported. For economic reasons the plant was closed down after the war. Processing of tungsten to the fine wire required for ordinary incandescent filament lamps was a costly process, and even the needs of Philips' factory, which made practically all the 16,000,000 lamps used in Australia each year, were not great enough to keep a local industry going.

Greenwood and Myers also worked on the small-scale production of tantalum wire and sheet from Western Australian ores. As it would have been uneconomic to keep this plant going after the war, it too was closed down and stored at Maribyrnong against a future emergency.

Another metal extracted for the first time in Australia, albeit on a small scale commercially, was titanium which was used as a "getter", a material for improving the vacuum in lamps and valves.[3] Extracted in the laboratories of A.W.A. by a modification of the Kroll process which had recently been evolved at the United States Bureau of Mines, this titanium was used in the local manufacture of valves.

The acuteness of the world-wide shortage of nickel at the time was reflected in the substitution for sheet nickel first of nickel-plated, cold-rolled steel, and finally of unplated cold-rolled steel. This improvisation was necessary in spite of the fact that nickel ores were available in nearby Noumea: smelting and extraction of nickel from ores had not then been undertaken in Australia.

Another special material required for valve manufacture was oxygen-free, high-conductivity copper, which was used in the manufacture of

[3] Titanium was first extracted on a laboratory scale by the CSIR Division of Industrial Chemistry, which supplied samples and details of the process to AWA.

copper-to-glass seals. Unless the copper was free from oxygen, it failed, when molten, to wet and adhere to hot glass. Copper of this quality, deoxidised with manganese, was, as mentioned earlier, developed by Metal Manufactures at Port Kembla, New South Wales, for use in the production of magnetrons and other valves.

Towards the end of 1942 when the United States Signal Corps indicated that it would no longer be prepared to accept orders for fabricated valve parts but would supply either complete valves or unfinished raw materials, the Department of Munitions through the directorate arranged for Philips to begin tooling up for the manufacture of most of the fabricated parts. While the A.W.V. Company was already making many of its valve components, Philips had up to this time been assembling valves almost entirely from imported components. Their output fell as a result of this diversion of their activities, but fortunately so did the demands of the Services.

Twenty-four types of valves of general utility, such as voltage regulators, carrier repeaters, thyratrons and high voltage rectifiers, were made. Philips developed an "all glass" valve—a type of construction which at the time was thought likely to supersede the method based on lamp manufacturing practice. The same company also succeeded in making 5-inch cathode ray oscillographs, but before it had gone far supplies from overseas were renewed and the project was dropped. The principal gaps in the production program were valves for sets working on direct current—sets of a type frequently used in outlying country areas. The Australian listening public, though it might not always have thought so at the time, for the execution of general repairs to radios was often difficult to arrange, suffered less inconvenience through wartime control of the sale and repair of civilian radios (according to experts of the D.R.S.S.) than did any other Allied nation.

During 1942 there was considerable confusion concerning the possibilities of substituting one kind of valve for another, with the result that equipment that performed satisfactorily in tests made as it left the factory might, when its valves were replaced in the field, perform poorly and endanger communications. It was clear that this state of affairs could not be allowed to go on. The problem was taken up by the Valve Production Advisory Panel, whose first action was to arrange for the introduction of uniform specifications for valves. The United States Signal Corps, which had experienced similar difficulties over lack of standardisation of valves, was in the process of drawing up its own specifications, and it was on these that the panel decided to base Australian specifications. These specifications simply defined the limits between which the physical characteristics of a particular valve must lie, but left the manufacturer free to meet these characteristics by using the methods and materials available to him. The scheme was a flexible one and yet ensured the necessary interchangeability of components. It also had the very desirable result that Australian manufacturers of valves for defence purposes achieved standards of production comparable with those of oversea manufacturers working to the same

specifications. Valves made later for civilian use also conformed to these new standards and thus the benefits continued after the war.

In 1944 valve manufacturers were asked to treat and pack their valves so that they could be stored and used in tropical climatic conditions without deterioration, and instructions for doing this were drawn up for their guidance.[4]

It would be fair to say that the war years saw a great increase in the self-sufficiency of the valve-manufacturing industry and that by the end of the war the industry was able to manufacture all the components that went into the valves required at that time. But this self-sufficiency fell away again after the war, principally for economic reasons. For example, the manufacture of even such an item as the special hard glass which Australian Consolidated Industries had developed for valves, was discontinued as soon as the war was over.

The critical position that arose in regard to the supply of materials for valves had an important lesson for the future. It was evident that to enable new technical developments to be launched it was not sufficient to set up and staff government laboratories and research institutions. These, of course, were necessary steps, but unless their activities were backed by the procurement of minimum quantities of special materials not normally available in the country but essential for new enterprises, a dangerous position might again arise. Much effort and ingenuity were expended to find substitute materials, but these were in general less efficient and less satisfactory than the materials originally called for. In some instances satisfactory substitution was impossible. Oversea supplies of one or two critical materials that could not have been made locally within a reasonable time almost certainly saved the Australian radar program from a serious impasse.

Stockpiling of materials without turnover of materials brought with it the risk of deterioration and obsolescence. One solution was to encourage selected local manufacturers to carry large stocks of vital oversea materials which could be used and replaced in the course of their commercial activities. This would have reduced to a low level the risk of losses and at the same time ensured that stocks were of up-to-date materials. The only call on the Government would have been the finance required to cover the difference in cost between the normal level of commercial stocks and the emergency level.

Radio equipment used by the Services could be divided, according to its size and complexity, into three main classes: light and not very powerful equipment which could be carried by one man, for use in the forward areas; larger and more powerful mobile equipment that could be carried either by several men or, more generally, by a truck; and the largest, most powerful, and more or less permanent installations. Each of these main classes could be further subdivided according as the equipment was used exclusively for transmission or reception, or for both.

[4] Interservices Specification 1001B. "General Requirements for Telecommunications Equipment in Tropical Climate", and MGO Aust 671A (Tropical Packaging and Packing).

The most important single communication project of the war was the Naval Shore Wireless Station at Belconnen near Canberra. When, in 1938, it was decided to build this station the plan was to install three 20-kilowatt high-frequency transmitters and one 200-kilowatt low-frequency transmitter complete with omni-directional and directional antenna systems for high frequency and a separate antenna system for low frequency. The contract for this equipment, which included the installation of a neighbouring receiving station at Harman (A.C.T.), was given to Standard Telephones and Cables Pty Ltd. The company prepared preliminary installation and layout drawings which, after consultation with authorities from the Departments of the Navy and of the Interior, were quickly incorporated into final building plans. In the meantime, work was proceeding on the design and construction of the 20-kilowatt high-frequency transmitter. The designs of this and the much more powerful low-frequency transmitter were to a large extent original though they did of course embody the best features of oversea equipment. By the time the 20-kilowatt high-frequency transmitters were ready for installation in 1939, the main buildings, antennae and other outdoor installations had been completed. These transmitters went into operation late that year. The 200-kilowatt low-frequency transmitter, which owing to its size took much longer to complete, was commissioned late in 1941 and went into full operation the day after Singapore fell. The specification for the transmitters stipulated that they were to be capable of operation for 18 hours a day with 6 hours for maintenance, but immediately after the fall of Singapore all transmitters were called upon to work 24 hours a day for three weeks without a break. They carried through this exacting program without a single interruption.

The largest single radio installation undertaken during the war was the transmitting station set up by the Postmaster-General's Department at Shepparton, Victoria, which was capable of effective short-wave broadcasting to any part of the world. This station, which comprised two 100-kilowatt and one 50-kilowatt short-wave broadcast transmitters, was intended primarily to broadcast propaganda to enemy-occupied countries. From information received after the war it was clear that "Radio Australia", as the station was called, did much to encourage the inhabitants and prisoners of war in those countries.

Building the station was a cooperative effort; arrangements for the site, buildings, emergency engine generating plant, transmission lines, antenna systems and specifications covering general performance of the transmitting equipments were the responsibility of the Postmaster-General's Department. The design and manufacture of the two 100-kilowatt transmitters were undertaken jointly by Amalgamated Wireless and Standard Telephones, who divided the work between them on a practical basis dictated by their previous experience and existing commitments.

The 50-kilowatt broadcast transmitter, which was imported from the Radio Corporation of America, was put into operation late in 1944, but the first of the two 100-kilowatt broadcasters did not go into service until August 1945, one day before "VP" day.

The importance of this project should not be minimised by the fact that it came into full operation only at the conclusion of the war. The contract was placed in 1942 at a time when the vital importance of effective propaganda in the Australian sphere of influence was just being recognised. No one then knew how long the war would last.

The most striking feature of the station was its size. It occupied more than a square mile, most of which was covered with a maze of aerials carried by fourteen 200-foot steel masts and transmission lines to feed these aerials. The radio equipment itself was housed in a blast-proof structure, and as a further precaution against being put out of action by a failure of the power supply, the station was provided with its own independent power station, equal to that found in many a moderately sized country town. With the exception of the engine alternator sets, the large modulation transformers and reactors, large vacuum tubes, vacuum condensers and a few miscellaneous components, all of the equipment was manufactured in Australia.

The P.M.G's Department designed and constructed—sometimes alone but often in collaboration with the Allied Works Council and other bodies —large numbers of lesser installations for the Services, including transmitting and receiving stations at army and air force headquarters, radio direction-finding stations for aircraft, radio homing beacons and army broadcasting stations at Darwin and Port Moresby.

A bare statement of the items of telecommunication equipment produced for the Services in Australia during 1939-45, although impressive, does not convey an idea of the obstacles which had to be overcome before these results could be achieved. First of all here is a list of items estimated to have cost approximately £12,000,000:

12,975 transmitters.
12,880 transmitter receivers.
13,396 communications receivers.
11,791 walkie-talkie sets.
20,000 broadcast receivers for Service amenities.

It will be recalled that in early stages of the war when it was believed that most Australian forces would be serving overseas with British formations, the policy was that local production of communications and signalling equipment should follow British designs as closely as possible. Difficulties immediately arose, mainly because local firms had very little information on manufacturing details for British equipment. The few examples of equipment held by the Corps of Signals were either of out of date or in a fairly worn condition; for more recent models only photographs or brief details of performance were available. These difficulties were accentuated by the fact that pre-war production of telecommunication equipment in Australia tended towards American rather than British practice. This was specially true of valves, and there were few machines in Australia adapted for manufacturing British types of valves. Consequently the manu-

facture of sets of British design was largely a matter of individual interpretation and it is not surprising that equipment produced under these conditions frequently had to undergo considerable modification before it conformed with operational requirements.[5] However, it is to the radio industry's credit that even in those early days, with so little experience and guidance, it was able to supply equipment for training and for shipment to Australian forces in the Middle East.

Formidable as were the difficulties arising from a lack of information on basic design and shortage of materials, and even greater difficulty was the Services' desire for interchangeability not only of complete equipments but also of accessories and components. The lack of standardisation of valves has already been alluded to.

It would have been difficult enough to keep the fighting forces supplied if equipment had been fully standardised, but in the difficulties present in 1942 the barrier to the production of any but the simplest items of signal equipment seemed unsurmountable. Both mechanical and electrical interchangeability were essential. Less difficulty was experienced in securing the former—the mechanical substitution of valves, for example, without alteration to mountings was not difficult to arrange. Electrical interchangeability was the real problem and one that was never completely solved during the war. A good deal was done to ease the situation by the Allied Services Radio and Signal Equipment Standardisation Committee (known as Committee "L") and by the Standards Association of Australia.

To keep pace with the changing conditions of war, improvements were being made overseas in the design of all types of communication equipment: in equipment for communication between members of the crew of an aircraft, or a tank; for communication between aircraft and between tanks. The increasing operational ceilings and ranges of aircraft and the introduction of supply-dropping from the air necessitated re-design of much equipment. Changes in design were also necessitated by the shift of fighting to the tropics.

Communication equipment had to be capable of withstanding the roughest and most severe conditions, including complete immersion in water. It was one thing to make light, portable equipment completely waterproof, but it was another matter to do the same for bulky, powerful transmitters. A unique instance of complete protection afforded to a set of this type was the Army Wireless Set 153,[6] a 300 to 500 watt long-range transmitter consisting of three units each weighing 150 pounds. All control spindles of this set passed through water-tight glands. Though it took a truck to move it, Set 153 was so designed that it would work efficiently during the heaviest tropical thunderstorm, even though it might be completely submerged in water for a time. In fact during a landing it could be thrown overboard and floated ashore without damage.

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[5] J. R. Edwards, "Some Operational Aspects of Services Equipment Design". *Radio and Electrical Retailer*, Vol. 23 (1946), p. 64.

[6] This was a tropic-proofed version of Set 133, which was used extensively by the army as a base station.

In November 1942 the army indicated that it required urgently and in large numbers a reasonably portable, light-weight, long-range, transmitter-receiver set for use in forward areas. The set was to be capable of the same performance as the British transmitter-receiver Number 22 but —and this is where difficulties were introduced—it was to be much more powerful (three to five times), lighter, fully tropic-proofed, and water-proofed so well that it would withstand complete immersion for half an hour without being incapacitated.

At the time of placing an order with the Radio Corporation Pty Ltd, Melbourne, for the development and production of pilot models, no design specification for this set existed, and it was left for the firm concerned to do its best, working in close collaboration with the technical officers of the army. At first engineers and manufacturers declared the specifications were impossible, and only through the dogged persistence of the contractor and the firm, and the continued insistence of the army, was the equipment made. Even so the first sets were made and delivered, in March 1944, only after relaxation of some items of the specifications.

By May 1944 most of the troubles were over and sets were being turned out at the rate of fifty a week. The complete equipment Wireless Set No. 22 (Aust.) weighed less than 40 pounds and was designed to split into three "man-pack" loads. The difficulties experienced with this equipment can be attributed, at least partly, to the absence of a laboratory to undertake the necessary research and development of radio equipment for the Services.

At times the difficulties of development and production were such that before the equipment could be made the need for it had passed. This was true of Wireless Set No. 19 Mark II. Intended in the first instance to be a copy of the corresponding British Set No. 19, so many modifications were suggested by different potential users that the contractor laboured for many months to meet all the requirements only to find, when success was in sight, that the equipment was no longer wanted and the order was cancelled. There was a very good reason for this. No. 19 was a short-range set designed for use under the extremely noisy conditions prevailing in tanks. It was a composite affair since it provided two separate systems: a telephone system to permit communication between members of the crew, and a transmitter-receiver to permit communication between one tank and another and between a tank and its headquarters. When the production of the Australian Cruiser Tank ceased, as it did in 1943, there was no longer any need for Set No. 19 Mark II.

Two transmitter-receivers used by all the Australian and Allied Services were Teleradio 3B (10 watts) and AT5/AR8 (known to the army as Wireless Set 112). The former was a commercial peacetime radio-telephone equipment which had been designed by A.W.A. to provide simple point-to-point communication in remote and sparsely populated areas. The network of teleradio stations established before the war at strategic points in the islands to the north of Australia was to play an essential part in the communications services of the area, and during the Japanese southward

drive formed a vital link in the navy's coastwatching service, which supplied information on the movement of enemy aircraft and ships.[7]

The communications receivers used by the Services were a very different affair from the domestic broadcast receiving set: they were far more highly selective—that is, they could discriminate far better between two closely adjacent wavelengths. The simplest way of illustrating the difference between the two receivers is to say that whereas the dial of a broadcast receiver might travel 9 inches to cover a range of frequencies, that of a communications receiver would travel, through a system of coils and switches, a distance of about 11 feet to cover the same range. A domestic receiver usually operated on 7 or 8 valves, while a communications receiver might use as many as 20 valves and cost anything up to six to fifteen times as much as a broadcast receiver. A typical receiver capable of operating either from an AC supply or from a battery, and one widely used in the South-West Pacific Area, was Reception Set No. 4 manufactured by Philips Electrical Industries.

Jungle warfare placed a new emphasis on radio communication, making it essential to reduce the weight of equipment as much as possible. This was especially necessary on patrol operations where troops had often to travel fast and far and at the same time maintain communications. Sometimes the nature of the jungle and the distances covered ruled out visual signalling and made telephonic communication too unwieldy. In these circumstances radio communication was the only satisfactory method. The first Australian wireless set designed specifically for operation in jungle areas was No. 208. In its complete form 208 consisted of two packages—one being the transmitter-receiver itself and the other a satchel containing battery power pack, headphones, signalling keys, spare valves and aerial wire. The entire equipment weighed less than 18 pounds and was easily transportable even under the most difficult conditions. To enable it to attain its maximum range of about 50 miles the set was designed to operate with an extended wire aerial instead of a telescopic rod. It was not intended for use on the move but for rapid installation at a fixed location.

No. 108 Mark III was another useful, easily portable transmitter-receiver consisting of a box worn on the back, a set of headphones, and two 6-foot telescopic aerial rods, which enabled communication to be maintained while units were on the move. This earned the set the name "Walkie talkie". It could be used for transmitting either the voice or morse signalling; with the latter a greater range could be obtained.

During a visit to Britain and the United States towards the end of 1943 Lieut-Colonel Jones (Director of Radio and Signal Supplies) was much impressed by the developments in miniature radio components. On his return he organised the visit to Britain and America of a government-sponsored mission comprising representatives of the Directorate of Radio and Signal Supplies and of commercial industry, to study the most recent

[7] See Eric Feldt, *The Coast Watchers* (1946).

trends in this field.[8] After spending about seven months abroad the mission returned to make a comprehensive report covering a good deal besides the trends in miniaturisation. However, these alone will be considered here.

In the United States the mission found that the radio industry, which before the war had produced a complete range of small components for use in miniature broadcast receivers of the type that fitted into a woman's handbag, had since concentrated on adapting these components for use in Service equipment. Modifications to improve stability, mechanical construction and tropic proofing were being introduced.

In Britain no very small domestic sets had been made before the war, and as a result it had been necessary to start from the beginning to manufacture miniature equipment for military purposes. This was not without advantages since tropic proofing and other Service requirements were kept to the forefront. The mission felt that in the long run British miniature components might well be more suited to tropical climates than those then being made in America. Information from both countries was sent back to Australia and slowly a program was got under way for the manufacture of miniature components, concentrating first on dry batteries of the "Minimax" type, details of which were supplied to Eveready (Australia) Pty Ltd by their American principals. Then miniature resistors, capacitors, sub-miniature valves (of the kind used in hearing aids), transformers and loud speakers were manufactured. Although some progress was made it came too late to be of any use in the provision of Service equipment. It was, however, of considerable assistance some years afterwards when the Commonwealth Acoustics Laboratories began to manufacture hearing aids for ex-servicemen.

The high-water mark of miniaturisation during the war was the proximity fuse, an essential part of which consisted of a radio transmitter-receiver not much bigger than an ice-cream cone. Devised in Britain, developed and manufactured on a large scale in the United States and Canada, the proximity fuse did much to defeat the V1 robot bomb. Its manufacture in Australia was not achieved until some years after the war.

In September 1939 the army was very short of field telephone equipment, especially switchboards, and to make matters worse it had very little technical information on this kind of equipment. There was, however, sufficient to enable S.T.C. to produce a switchboard which could be made from standard components and which was interchangeable with the one used by the British Army. Beginning in June 1940, the company made large numbers of switchboards over the next few years. A few months later it was ready to manufacture the field telephones as well, and supplied tens of thousands to the fighting forces.

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[8] The Aust Radio Mission (Apr to Dec 1944) consisted of W. J. Richards, Controller, DRSS (Leader); T. H. Skelton, Washington Representative, DRSS; C. S. Gittoes, Ducon Condenser Pty Ltd; A. Freedman, Stromberg-Carlson (A/sia) Pty Ltd; W. J. McLellan, International Resistance Co A/sia Ltd; O. C. Oppenheim, Radio Corporation Pty Ltd; R. C. Cox, Philips Lamps (A/sia) Pty Ltd; and F. R. White, A.W.A. Ltd.

The war saw a great increase in the demand for direct current for many purposes—for operating telephone exchanges, carrier telephone and telegraph terminals and repeaters for the armed services. Practically every R.A.A.F. servicing depot in Australia was equipped with an electroplating unit which required direct current for its operation. Of the several different kinds of rectifier then in general commercial use the selenium rectifier was most in favour; it was more robust than the glass rectifier tubes and, at low voltage, more efficient than the mercury-vapour rectifier. Perhaps its greatest single advantage was the wide range of power output (from milliwatts to kilowatts) of which it was capable. The vital part of the rectifier consisted of a group of selenium discs or plates connected together in series or in parallel according to the output of voltage and current required. Selenium, in common with other members of a class of materials known as semi-conductors, had the property of allowing an electric current to flow through it in one direction much more readily than in the opposite direction; it was to this characteristic that selenium owed its ability to function as a rectifier.

The selenium rectifier first came into commercial use in Germany in 1927. Until 1938 its use was confined to Europe, where it experienced a remarkable growth in public favour. In 1938 its use spread to Britain and the United States and in the following year to Australia. It was first manufactured in Australia by Standard Telephones and Cables Pty Ltd from imported selenium plates. This practice continued until shortly after the outbreak of war when the management of S.T.C., anticipating the demands of the Services and the possibility of being cut off from oversea supplies, decided to manufacture the selenium plate locally. This decision was arrived at after taking into consideration the difficulties likely to arise in undertaking a new industry without the services of staffs familiar with processes which at that time had no counterpart in the Commonwealth. Fortunately selenium could be recovered as a by-product of the electrolytic refinement of copper at Port Kembla. O. T. Lempriere and Co Ltd undertook to supply "spectrographically pure" selenium. Purity was all important: the presence of the most minute traces of some foreign substances could completely destroy the rectifying action of selenium. "Spectroscopically pure" proved too vague a specification and was replaced by one setting out the upper limits to the amounts of the different impurities which could be tolerated. These limits were so small—they were of the order of a few parts per million—that it was no great surprise when the two companies disagreed over some of their analytical results. In the end it was agreed that each batch of purified selenium should be accepted or rejected on the basis of a production test, that is, on its performance when a sample was made up into a trial rectifier.

Difficulties were encountered in making the selenium into discs, and were only overcome after considerable scientific and developmental work had been carried out. Nevertheless, the first unit incorporating Australian-

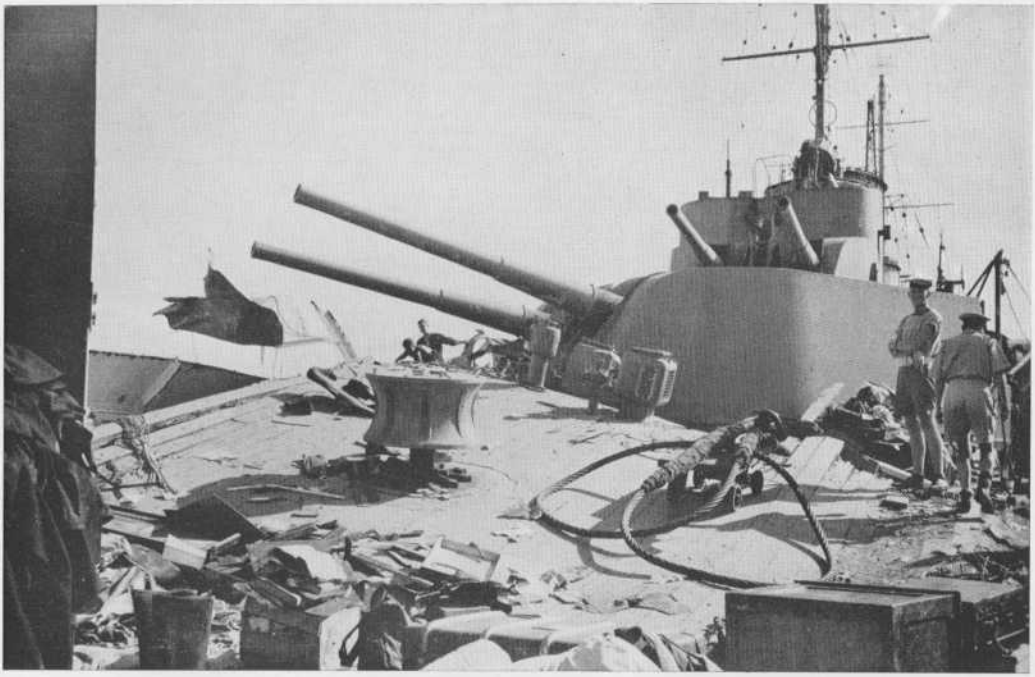
made selenium plates was ready for delivery in February 1942. Thereafter they were made on a scale sufficient to meet both military and civilian needs.

With the setting up of Allied Headquarters at Port Moresby the need arose for a speedy and reliable means of communication between New Guinea and the mainland of Australia to supplement the existing radio-telegraphic and telephonic circuits. The most satisfactory way of achieving this was an undersea cable, since by this means hundreds of messages could be sent every minute irrespective of atmospheric conditions, which were so often unfavourable in the tropical regions to the North of Australia, and without the enemy being able to listen. As cable was unprocurable it was decided to retrieve two old cables from Bass Strait and re-lay them. While the operation of re-laying was in progress, the ship engaged on the work was caught in a severe gale at night and 60 miles of cable was swept away. The only solution, if the line was to be completed in a reasonable time, was to replace the lost cable by one made locally. Although this type of cable had never before been made in Australia, its manufacture presented only one real difficulty: that of procuring a suitable insulating material, since gutta-percha was not obtainable. After some investigation it was found that the plastic polyvinyl chloride was now available. Several firms were concerned with manufacturing the cable, the final stages of which were carried out by Metal Manufactures Ltd at Port Kembla.

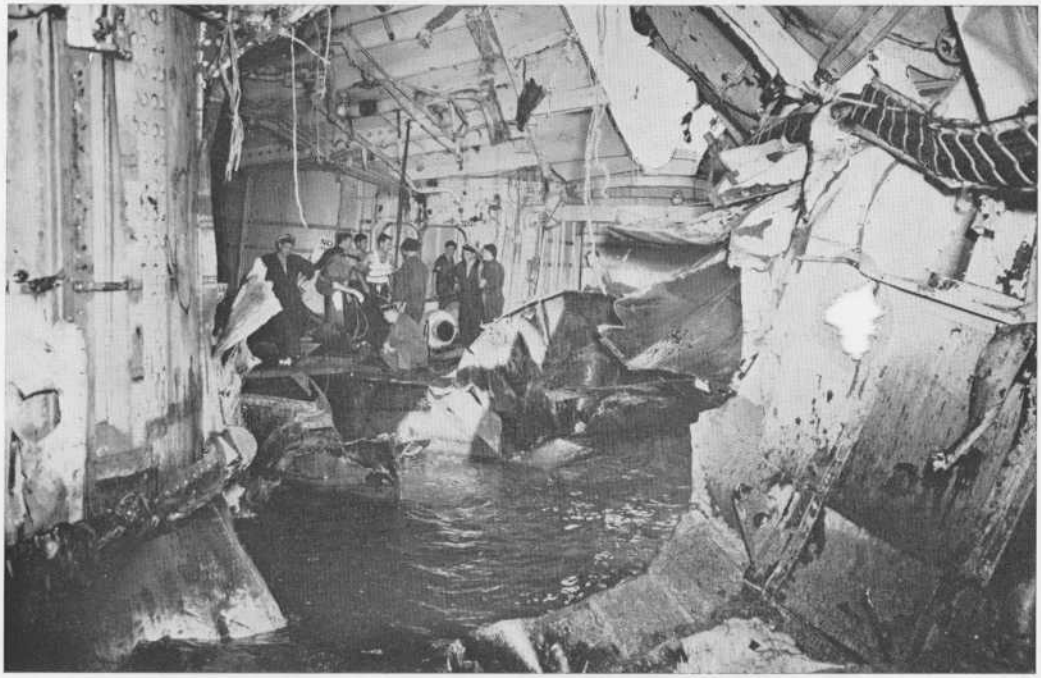
Trials were later made with polythene as an insulating material. Research engineers of the P.M.G's Department developed light coaxial submarine cables insulated with polythene for use principally in shallow waters between islands in the Pacific where the distance to be covered was less than 50 miles. These cables were designed for carrier systems using frequencies up to 30 kilocycles per second.

The P.M.G's Department increased its use of multi-channel systems during the war. These systems, which enabled as many as eighteen conversations or sets of morse signals to be carried simultaneously on one line, greatly increased communication. Originally developed in the Bell Telephone Laboratories in the United States about 1929, these systems were introduced in Australia in the late thirties. Most of the carrier equipment used in Australia up to and during the war was developed by S.T.C. and Communication Engineering Pty Ltd, using oversea designs as a basis. New lines and circuits were built from Adelaide to Darwin, Adelaide to Perth, Brisbane to Hughenden to Darwin, Brisbane to Cairns, and Townsville to Cape York—25,000 miles in all. Much of this was done with the help of the Services but the purely technical side of it was the responsibility of the Postmaster-General's Department.

To make telephone equipment as light as possible, engineers of the P.M.G. introduced the use of die-cast alloys of aluminium and zinc. Some difficulties were experienced at first with both pressure and gravity die-

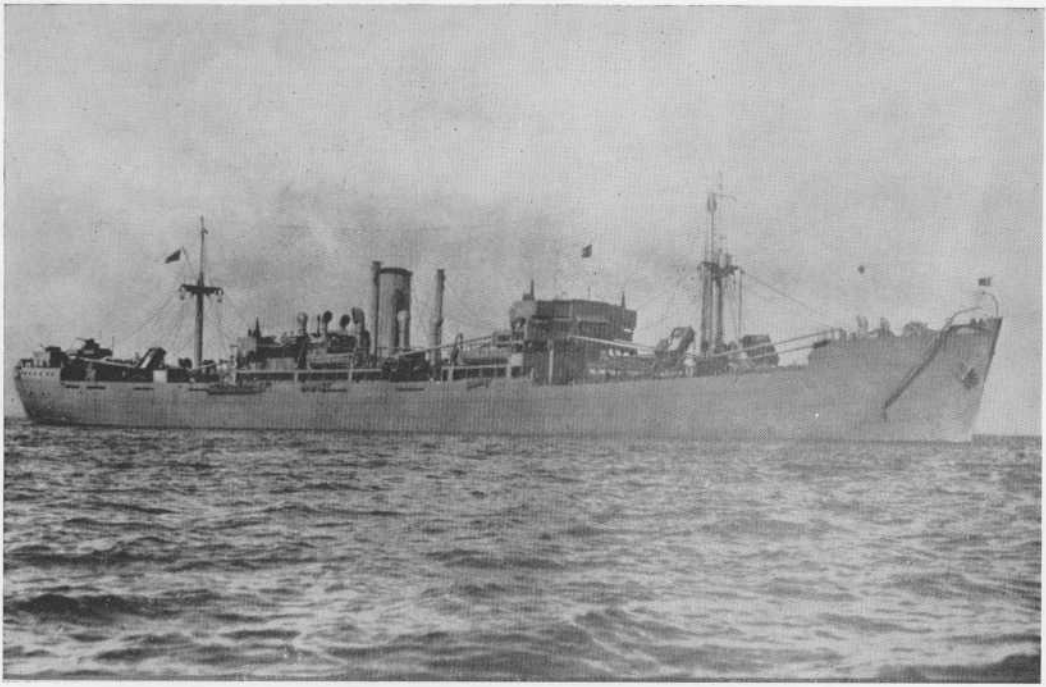


Torpedo damage to H.M.A.S. *Hobart*: view from fantail looking forward.



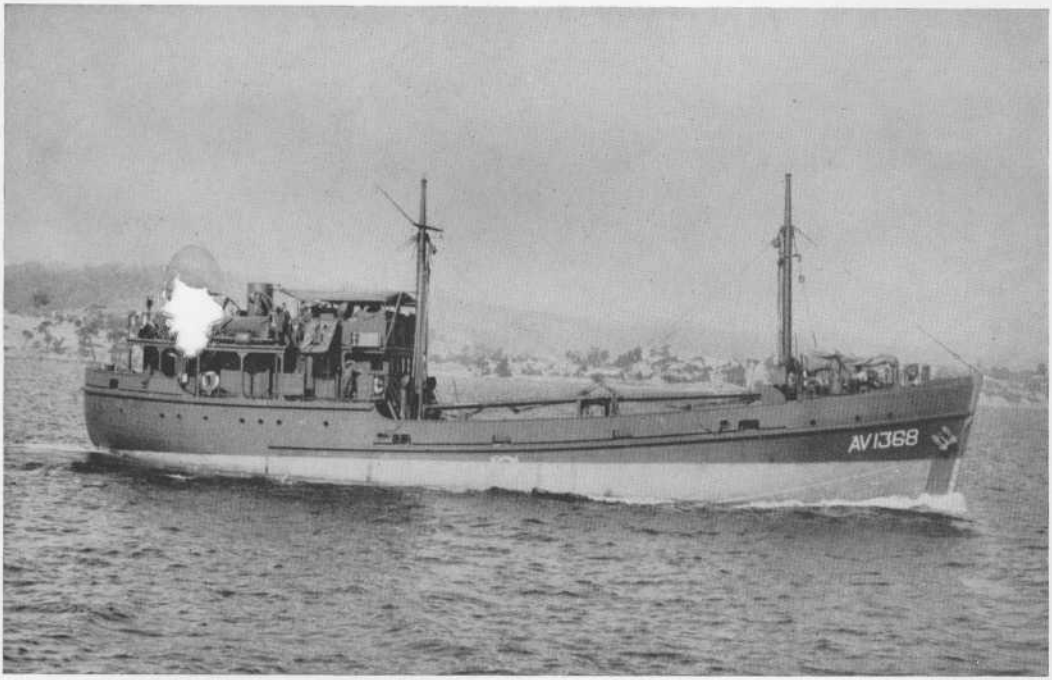
(*R.A.N.*)

Torpedo damage to H.M.A.S. *Hobart*: view looking aft from centre line of wardroom.



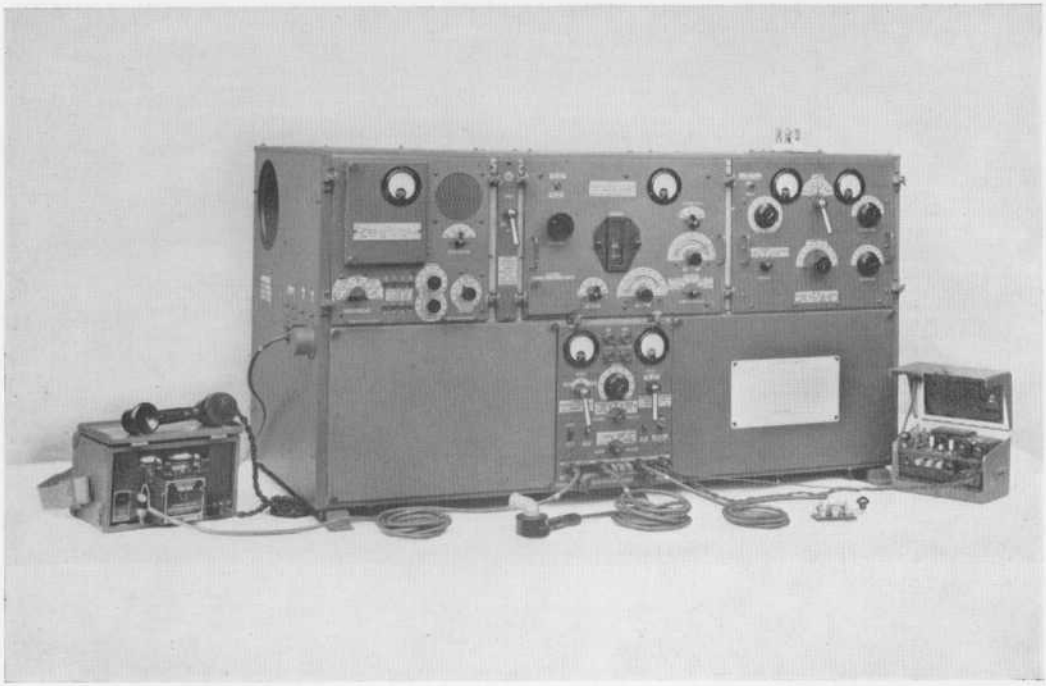
(*News and Information Bureau*)

Australian merchant ship *River Clarence*.

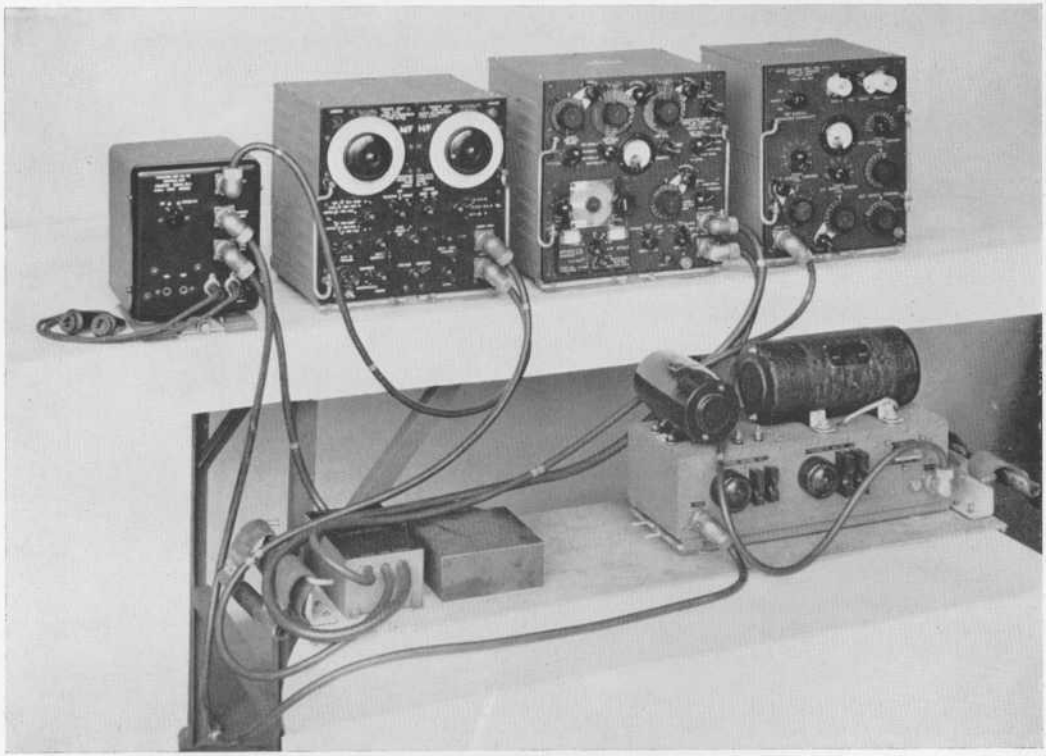


(*The Mercury, Hobart*)

Wooden cargo vessel of 300 tons built at Glenorchy, Tasmania.



Wireless Set No. 133. *(A.W.A.)*

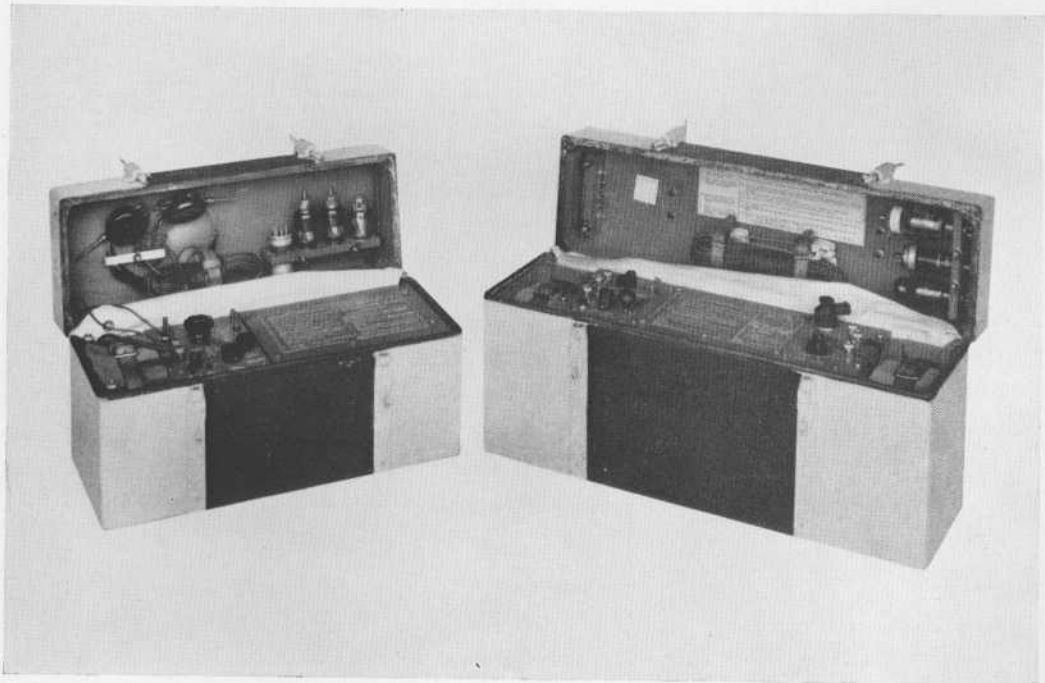


AT.5/AR.8 Transmitter-Receiver. *(A.W.A.)*



(*Dept of Information*)

A.W.A. Teleradio equipment operating in a forward jungle position during the action which ended in the capture of Mubo.



(*A.W.A.*)

Lifeboat Receiver and Transmitter in water-tight cases.

casting since these techniques were new to local industry, but they were eventually overcome.

On a somewhat lower technological level, but none the less important, was the design and manufacture of supports for telephone lines in operational areas in Northern Australia. In response to an appeal by the army for a telegraph pole which would be light enough to be carried by air or even by hand, and resistant to deterioration in a tropical climate and to attack by termites, the P.M.G. Department adapted the design of a steel pole that had been developed in Britain. The pole consisted of sections 6 feet long and pressed from sheet steel so as to have an elliptical cross section. The sections were tapered so that they could glove together, or nest telescopically in one 6-foot length for transport. Almost 250,000 of these poles were manufactured by Messrs K. L. Engines and Tractors Pty Ltd of Melbourne, who also built radio masts of similar construction but employing larger sections.

The P.M.G's Department also acted as major coordinating contractor to the D.R.S.S. for the supply of a whole range of general signal equipment covering such items as daylight signalling lamps, heliographs, Fullerphones, and microphones.

Among other items not previously made in Australia was the hot-wire microphone, a device developed during the 1914-18 war for locating guns. The sound wave or pulse from gunfire caused a transient cooling of an electrically heated wire, and this resulted in small changes in the electrical resistance of the wire which could be detected with an ordinary microphone. In sound ranging, at least three hot-wire microphones were set up at points not in a straight line; the time of arrival of sound waves from a given source was noted at each microphone; from these data the location of a gun could be worked out.

As part of their training pilots of the R.A.A.F. were given experience in low-pressure chambers under conditions simulating those they would meet in flying at great altitudes. The class, consisting of about fourteen pilots and a medical officer-in-charge, would, while in the chamber, be provided with communication equipment that they would later use in service. In this way the P.M.G's Department tested amplifiers used for communication between pilots wearing oxygen masks under low-pressure conditions, where the efficiency of the voice and electric-acoustical instruments was far from normal.

Though hampered through the general lack of detailed planning and by the absence of any systematic attempts to control the quality of its raw materials, the radio industry achieved a fine record of production. This is not to say that things could not have been done better had there been more preparation, more time, more trained manpower and a telecommunication research laboratory. Specifications for materials and components were the exception rather than the rule up to 1944. The inadequate training of Service inspection staffs coupled with the lack of testing equipment noted earlier, made it impracticable to adopt other than the most rudi-

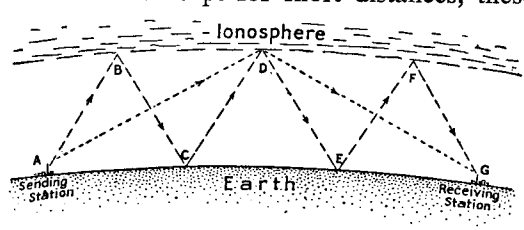
mentary acceptance tests. Lack of standardisation and lack of specifications and the means of making proper specification tests contributed to the ineffectiveness of much inspection. Design divisions of the Services were not sufficiently familiar with the permissible tolerances in manufacture and frequently failed to recognise the advantages of "freezing" a design for production, a shortcoming by no means peculiar to the radio industry.

THE PREDICTION OF CONDITIONS FOR RADIO COMMUNICATION

At first sight it might appear that radio telegraphy and telephony, independent as they were of material contacts between transmitting and receiving stations, offered such advantages that they would be used to the exclusion of all other methods of communication. They were of course widely used and offered in many instances the only means of communicating over long distances and between moving points, as from ship to ship, from aircraft to ship, from aircraft to aircraft and from ship or aircraft to base, or to troops on the ground. Nevertheless they suffered from three disadvantages: they were neither completely secret nor completely reliable for communicating messages, and the sender could be located by direction-finding techniques. Great improvements were made in the reliability of radio-telegraphy and radio-telephony during the war of 1939-45.

Early in the war it was fairly common for radio communication between two distant stations to fail completely; when this happened the operators naturally blamed their equipment. Much time and effort were wasted in taking equipment to pieces and searching for non-existent defects when in fact the ionosphere was the cause of the failure.[9]

The radio waves most effective for medium- and long-distance communication (anything over about 100 miles) were those with wavelengths ranging from 300 down to 10 metres.[1] Except for short distances, these waves travelled from transmitter to receiver along an indirect path via the ionosphere. The strength of the high-frequency signal carried by the "ground wave" (that is, the direct wave) fell off rapidly with increasing distance from the transmitting station. Hence the ground wave was important only for communication between centres not more than about 100 miles apart. Between more distant stations, short-wave radio-communication was by means of sky waves—that is, waves reflected from the



[9] The ionosphere, so called because it is ionised (i.e contains electrons and positively and negatively charged atoms and molecules which are known as ions) is a region of the earth's atmosphere extending from about 70 to 300 Km above the earth. The structure of the ionosphere is by no means simple. Definite stratification of the ionisation into layers has been observed and 3 regions are now recognised, and known in ascending order of height as the D, E and F regions. F is not only the highest but also the region of densest ionisation.

[1] These are also referred to as *high frequency* waves with frequencies from 1 to 30 megacycles per second corresponding to the above wavelengths. This section deals throughout with short-wave or high-frequency radiations in this range.

ionosphere. For distances up to 2,000 miles one reflection only (ADG in figure) was usually involved; multiple reflections (ABCDEFG) did occur but since there was a loss in signal strength at each reflection, waves travelling along the more complex paths did not normally make any important contribution to the strength of the signal received at G.

The most important of the electrically-charged particles implicated in the reflection of radio waves by the ionosphere were the free electrons ejected from atoms by the sun's ultra-violet radiation. The density of electrons in any region of the ionosphere depends on the intensity of the sun's radiation and therefore varies with the time of day and season of the year. Since the efficacy of the ionosphere as a reflector of radio waves is largely determined by the density of free electrons present in it, changes in electron density were of great practical importance in radio communication. During the hours of darkness the process of ionisation ceases and many electrons disappear owing to their tendency to recombine with positive ions. But before they all recombine, the charging process begins again with the rising of the sun. Because of the resulting rapid changes in the ionosphere at sunrise, an aircraft on dawn patrol—submarine hunting perhaps—might temporarily be cut off from radio contact with its base. When this kind of failure occurred a suitable change of wavelength would usually overcome it. The problem was to determine what this change must be.

For a given density of ionisation in one or other of the reflecting regions of the ionosphere there was an upper limit to the frequency of the signal that could be reflected. This was known as the critical frequency. Waves of higher frequency penetrated the ionosphere and were lost to outer space. Owing to the fact that absorption of radio waves in the lowest region of the ionosphere (the D region) increased to a marked extent as their frequency decreased, it was essential to operate with frequencies near but lower than the critical frequency if the use of excessively powerful transmitters was to be avoided. For this reason communications officers were continually exercised to locate the "maximum usable frequency". In practice the best signals resulted when the wave frequency was about 15 per cent below that which would just penetrate the ionosphere.

In the decade before the war fundamental studies of the ionosphere had been initiated at several centres throughout the world, and instruments had been developed to measure its most important characteristics, the critical frequency and equivalent height[2] of the various layers. The most useful of these instruments were automatically operated and provided a record, at regular intervals throughout the day and night, of these characteristics of the ionosphere. Instruments of this type were in operation at Slough (England), Washington D.C. (United States), Huancayo (Peru)

[2] To observe the equivalent height a radio signal was sent vertically upwards and picked up again, after reflection at the ionosphere, by a receiver close to the transmitter. From the time of travel the height of the reflection could be calculated, but since radio waves travelled more slowly in ionised regions the result obtained was somewhat greater than the true height: it was known as the "equivalent height". The critical frequency was obtained by gradually increasing the frequency of the exploring signal and noting that at which the ionosphere was just penetrated; that is, when no further echoes were obtained.

and Watheroo and Canberra (Australia) for various periods before the outbreak of war, and provided data from which the broad pattern of behaviour of the ionosphere on a world-wide basis was known.

The first attempt at using these data for predicting the best frequencies for radio communication was made by the United States Bureau of Standards (about 1938), using the observations that had been made at Washington. Analysis of the data collected at other ionospheric recording stations, carried out by different observers, showed sufficiently definite trends to serve as a basis for such predictions, but no attempts were made to coordinate all the available information. The problem of predicting the optimum frequency for communicating between two given points at a given time was satisfactorily solved only after a detailed study had been made of the diurnal and seasonal changes in the ionosphere over practically the whole of the earth's surface. That Australia was able to play a major role in solving this problem was in large measure due to the foundation work of the Radio Research Board. Its influence here was just as important as it had been in solving the problems of radar. Without the trained men and equipment provided by the board little headway could have been made with the prediction of conditions for radio-communication.

The first ionospheric recorder in Australia was built in 1935 by Dr Pulley, and the first ionospheric station to be equipped with automatic recording was set up at the Commonwealth Solar Observatory as early as March 1937. This equipment, which was originally designed by Mr H. B. Wood,[3] was operated by Mr Higgs[4] and later replaced by an automatic recorder of wider frequency designed by him. Thus was begun a long series of observations, designed originally to throw light on the nature of the ionosphere, that were later to serve a highly practical purpose.

A systematic study of the observations made at Canberra was initiated by Mr F. W. Wood,[5] who as an officer of the board had been interested in predicting conditions in the ionosphere for the Royal Air Force while working at the Royal Aircraft Establishment, Farnborough, before the war. Wood and his staff at the Sydney laboratory of the Radio Research Board had substantially completed this analysis by late in 1940. An important contribution to the application of ionospheric data to the prediction of communication frequencies had, in the meantime, been made by Dr Martyn, with the discovery that there was a simple relation between the critical frequency at vertical incidence, and the maximum frequency that could be used at oblique incidence without penetrating the ionosphere.

Changes in the main (F_2) region of the ionosphere, however, proved to be more complex than had at first been suspected. In addition to the more or less regular diurnal and seasonal fluctuations in the density of the different regions of the ionosphere, brought about principally by the

[3] Lt-Col H. B. Wood, OBE, ED; BSc, ME. Radio transmission engineer; CRE 3 Armd Div, 11 Div, 3 Div; Chief Engineer, Standard Telephones and Cables, since 1946. B. Sydney, 21 Jun 1909.

[4] A. J. Higgs, BSc. Assistant, C'wealth Solar Observatory, 1926-40; Research Officer, Radiophysics Lab, 1940-45, Technical Secretary since 1945. B. Sydney, 6 Jan 1904.

[5] F. W. Wood, DSc, PhD. First Assistant, Watheroo Magnetic Observatory, 1926-33, Director 1946-49; Officer-in-charge Radio Research Board 1939-46. Of Sydney; b. Albany, WA, 12 Jun 1905.

changing zenith distance of the sun, there were other fluctuations caused by changes in the sun itself. It was well known that the average number and area of spots on the sun increased and diminished in cycles of about eleven years; similar fluctuations were believed to occur in the sun's output of radiation, especially in the ultra-violet part of the spectrum, which, it will be recalled, is the agent mainly responsible for ionising the earth's upper atmosphere. These fluctuations have a marked effect on the F_2 region of the ionosphere, the uppermost and densest region and the one by means of which most long-distance short-wave communication took place.

The analysis of observations at Canberra confirmed that in general the greater the sunspot number the denser the ionosphere.[6]

As early as 1940 the results of this analysis had revealed that though the conditions in the ionosphere are very variable they possess sufficient direct correlation with sunspots to be predictable with a fair degree of accuracy, provided that the sunspot number is known. By 1945, when several ionospheric recording stations had been in operation over a complete sunspot cycle, it was confirmed that there is a roughly linear relationship betwen maximum usable frequency and sunspot number. Sunspot numbers could thus be used with observed values of the critical frequency to predict maximum usable frequencies. Fortunately observations of sunspots which have been made over many decades show that the sunspot number follows a very regular cycle. Therefore the sunspot number for any particular month can be predicted with a considerable degree of accuracy many months in advance. This fact proved to be the key to accurate prediction of ionospheric conditions. Predictions for local operations usually took the form of graphs showing the maximum usable frequency for distances up to 2,000 miles—that is, for transmissions involving principally one reflection from the ionosphere. Such graphs were prepared for each 10 degrees of latitude and showed the average values for that month for each hour of the day, issued three months in advance.

In December 1940, at the suggestion of Pilot Officer Hall,[7] the Department of Air asked the Watheroo Observatory[8] and the Radio Research Board to supply regularly information on the state of the ionosphere, which would enable it to allocate frequencies for use in communication between all points of interest to the R.A.A.F. The department pointed out that the information was needed urgently because failures were occurring in communication at times of the day when continuity was essential.

The Radio Research Board and the Watheroo Observatory began to prepare information (in the form of graphs) showing predicted maximum

[6] It has been found that the activity of the sun can be better described by taking into account both the number of individual spots and their association in definite groups. Wolfer, of Zurich, Switzerland, devised a system wherein this was specified by an index obtained by multiplying the number of separate spotgroups by ten, and adding the number of individual spots. This number was widely used to indicate solar activity and was known as the "sunspot number".

[7] S Ldr A. L. Hall. Radio Inspector, PMG's Dept. Of Moonee Ponds, Vic; b. Melbourne, 5 Mar 1909.

[8] The Magnetic Observatory at Watheroo (WA) was built and operated from 1918 to 1947 by the Department of Terrestrial Magnetism, Carnegie Institution of Washington. It was later given by the Carnegie Institution to the Commonwealth Government and operated by the Bureau of Mineral Resources, Geology and Geophysics of the Department of National Development.

usable frequencies for communication at any given time between any two stations in Australia. At first the information was supplied only to the R.A.A.F., but it was not long before the army and the navy began to ask for it. Each Service had its own peculiar problems in communication, and each had its own preference for the manner in which the predictions should be presented. The navy preferred its data in the form of tables that the layman could follow, and insisted that all distances should be given in nautical miles; the air force preferred curves and contours because these gave more complete information, especially for mobile units; the army preferred curves for a particular latitude, since a whole force could work on the same curve for long periods.

To extend observations of the ionosphere, additional automatic recorders (designed and built in the Radiophysics Laboratory, Sydney, under Higgs' direction) were installed at Sydney, Hobart, Brisbane, Townsville and Cape York, and also in New Zealand, Fiji and Christmas Island in the Pacific.

In the hope of promoting a discussion of the wider implications of ionospheric prediction, a conference of all interested Service and scientific organisations was called in September 1942 at the instigation of the Department of Air and at the invitation of Sir John Madsen, Chairman of the Radio Research Board. Acting on a recommendation made by the conference, the Radio Research Board formed the Australian Radio Propagation Committee, whose functions were to provide direct liaison between the fighting Services and the scientific laboratories so that the practical needs of the Services could be more effectively met. The committee also maintained close contact with corresponding organisations in Britain and the United States to promote world-wide coordination of the ionospheric activities being carried out by the Allied nations.[9]

The need for coordination became apparent when attempts at prediction were made for the South-West Pacific Area by the British service (based on London), the American service (based on Washington) and the Australian service (based on Sydney). Frequently all three sets of predictions differed. A particular difficulty arose in New Guinea. The Australian prediction service had assumed that data gathered by the station at Huancayo (Peru) would apply also to Port Moresby (New Guinea), which is at about the same latitude; it was found, however, that signals were not getting through on the frequencies predicted. Predictions were so completely at variance with experience that doubt was cast upon the validity of the methods used by the prediction service. Action was promptly taken to remedy this.

A conference of representatives from Britain, America, Australia, New Zealand, South Africa and China met in March 1944, in London for the first session and in Washington for the second. The conference agreed that

[9] The committee initially consisted of: Chairman, Prof F. W. G. White (Radiophysics Laboratory and New Zealand); Dep Chairman, Sir John Madsen (Radio Research Board); Secretary, F. W. Wood (Radio Research Board); Conjoint Sec, S Ldr A. L. Hall (Dept of Air); Members: Lt O. M. Moriarty (Dept of Navy); Lt-Col B. F. A. Brown (Dept of Army); Dr R. v.d.R. Woolley (C'wealth Solar Observatory); Dr C. W. Allen (C'wealth Solar Observatory); E. J. Stewart (PMG's Dept); Observer, Lt G. W. Hanna (GHQ, SWPA).

information concerning ionospheric conditions had been coming in from stations all over the world in such large quantities during the war years that there had not been time or opportunity to assimilate and appreciate its full significance. The most cursory analysis showed, however, that there were great differences in the ionosphere in different parts of the world. Groups of investigators, it was realised, had been trying to solve problems of global proportions on the basis of data applicable only locally. Also, wartime conditions hampered discussion between workers. Only after all the information had been pooled and systematised was it possible for satisfactory global predictions to be made. The exchange of information and views at the conference made a very good start in this direction.

A clue to the inconsistency of the predictions made for New Guinea was revealed by scientists at the Bureau of Standards, who noticed that ionospheric conditions at stations in America just north of the equator were very similar to those at stations just south of the equator on the opposite side of the earth. This asymmetry of the ionosphere about the geographic equator was traced to the fact that the geomagnetic equator was a controlling factor. In the neighbourhood of Port Moresby the geomagnetic equator was about 12 degrees north latitude, while at Huancayo it was about 12 degrees south latitude. As data became available from more stations, including new ones established by the Radio Research Board at Brisbane, Townsville and Cape York, Queensland, and at Hobart, the correctness of this interpretation was confirmed. By taking into account the influence of the geomagnetic equator, many of the earlier inconsistencies in prediction disappeared.

The Japanese had earlier become aware of the significance of the geomagnetic equator and had set up a string of observing stations along it. From a scientific viewpoint the Japanese data were reliable, but they were presented in a form for use only by experts. However, Japanese scientists were not able to convince their Services of the usefulness of ionospheric predictions, and the value of these excellent observations was largely lost.

By the end of 1944 the accuracy attained in predicting ionospheric conditions in the South-West Pacific Area was about 90 per cent, a reliability already achieved in other areas. The residual 10 per cent unreliability was due largely to the fact that conditions in the ionosphere are seriously influenced by major unpredictable disturbances on the surface of the sun. Occasionally conditions in the ionosphere are so strongly affected by solar "flares" and magnetic storms—phenomena associated with sunspots—that a complete blackout in radio communications takes place all over the world. Early in the history of ionospheric prediction Australian scientists realised that day-to-day predictions would be upset by individual sunspots or groups of sunspots, but for some time there was no clear idea how to estimate their probable effects. The Australian Radio Propagation Committee asked Dr Allen[1] of the Commonwealth Solar Observatory, who

[1] C. W. Allen, DSc. Assistant, C'wealth Solar Observatory, Canberra, 1926-51; Prof of Astronomy, University College, London, since 1951. B. Perth, WA, 28 Dec 1904.

had for many years made an intimate study of solar phenomena, for his cooperation in attacking the problem of forecasting sudden disturbances.

Although the *average* number and area of spots increases and decreases in cycles of about 11 years, individual spots appear in rather a sporadic manner. Furthermore the disturbing influence on the ionosphere of any particular spot is erratic and quite unpredictable. By means of a solar telescope and a spectrohelioscope, Allen kept a watch on the activity of abnormally large, persistent spots and prominences which could cause severe magnetic storms. When a storm appeared to be imminent, as the result of the approach of an active sunspot to the sun's central meridian, urgent warnings were sent to the Services. The sun rotates once in 27 days and sunspots and other sources of magnetic disturbance tend to recur every 27 days. The recurrent storms could thus be predicted with reasonable accuracy and were the main disturbances during 1942-44, a period of maximum sunspot activity.

Towards the latter part of the war the use of ionospheric prediction became general throughout the Allied nations. Predictions for average conditions provided by the Radio Research Board, and the forecasts of disturbances from the Commonwealth Solar Observatory, were greatly appreciated by all the Australian Services and did much to enhance the reliability of communication. Since radio communication was widely used, the value of this improvement, particularly in areas such as New Guinea where no previous experience existed, was clearly quite considerable because it made communication possible nearly 100 per cent of the time.

After the war improvements continued to be made in ionospheric prediction, and its importance in everyday radio communication led to the setting up of a permanent Australian Ionosphere Prediction Service under the aegis of the Department of the Interior.

The vast amount of ionospheric data collected from all over the world proved invaluable in permitting the building up of a much more complete picture of the higher regions of the earth's atmosphere. The structure of the ionised regions is now reasonably well known; also their regular daily and seasonal variations which depend on the sun's radiation. The occurrence of tidal motions in the upper atmosphere has been fully confirmed. The hypothesis of Balfour Stewart in 1882 that variations in the earth's magnetic field were due to currents in the upper atmosphere has been fully substantiated, and many of the details of his theory have been worked out in terms of the electrical characteristics of the upper atmosphere. A great deal also is now known of the transient and irregular changes in the upper atmosphere due to radiation from particular regions of the sun associated with sunspots, and the possibility of forecasting the irregular disturbances to communications has greatly improved.

This fine example of the practical application of pure science is a great tribute to the wisdom and foresight of Sir John Madsen, who initiated and supervised research on the ionosphere in Australia, and to the officers of the Radio Research Board and the students and staff of Australian universities whose work extending over many years laid the scientific foundations

upon which prediction of the conditions for radio communication was based. In the post-war period Australia became fully established as an important world centre for ionospheric research.

ACOUSTIC RESEARCH

Following a lead given by the R.A.F., the R.A.A.F. set up a Flying Personnel Research Committee which in turn appointed sub-committees to deal with hearing, vision, air sickness and other physiological problems connected with flying. There was little difficulty in finding problems on which work should be done but it was another matter to find laboratory facilities. The Flying Personnel Research Committee therefore turned for help to the National Health and Medical Research Council,[2] which not only financed the research to be undertaken but recruited civilian scientists to do it.

Ample facilities for studying the physical problems of light existed in the National Standards Laboratories and were used by the sub-committee dealing with vision. However, little or no provision had been made in these laboratories for work on sound, since the needs for standards appeared to be much less pressing in this field than in those of light, heat and electricity. At the time there were difficulties in securing the necessary specialists in sound, and it was also evident that a good deal of the work of a sound laboratory would be physiological in character. Dr Eccles,[3] then the Director of the Kanematsu Memorial Institute of Pathology at Sydney Hospital and an authority on the physiology of hearing and sight, urged the National Health and Medical Research Council to establish laboratories for research in acoustics.

The Services were concerned about two main problems likely to arise in war: (1) communication under conditions of excessive noise; and (2) the harmful physiological effects of excessive noise occurring round guns. There was little difficulty in persuading the Commonwealth Government to provide funds through the National Health and Medical Research Council for equipping special laboratories, consisting mainly of soundproof rooms with appropriate instruments for studying the physical characteristics (pitch and intensity) of noise, and the effect of noise on men and communications.

The Acoustics Research Laboratory under Dr Eccles was first set up in the Kanematsu Institute but soon after transferred to the New Medical School at the University of Sydney under Mr Murray,[4] who had been seconded for this purpose from the Postmaster-General's Research Laboratories in Melbourne. Murray, who had specialised on problems of speech and hearing in communications, was given the assistance of other physicists

[2] Chairman: Dr J. H. L. Cumpston, Director-General of Health.

[3] J. C. Eccles, FRS, MA, DPh, MB, BS. Director Kanematsu Institute of Pathology, Sydney Hospital, 1937-43; Prof of Physiology, Univ of Otago, NZ, 1943-51; Prof of Physiology, National Univ, Canberra, since 1952. B. Melbourne, 27 Jan 1903.

[4] N. E. Murray, BE, BSc. Engineer, PMG Research Labs, 1934-42; Director, Acoustic Research Lab, Univ of Sydney, 1943-46; Director, C'wealth Acoustic Laboratories, Dept of Health, since 1947. B. Perth, WA, 2 Nov 1908.

and physiologists from the army and air force and arrangements were made to enlist the help of a number of medical students to act as "guinea pigs".

One of the first subjects to receive the attention of the laboratory was the problem of increasing the efficiency of communication under the excessively noisy conditions prevailing in tanks and aircraft. Where communication between members of the crew of a tank or an aeroplane was by means of telephone, as it generally was, the main concern of the Acoustics Laboratory was to design earphones which would exclude as much external noise as possible. In many training aircraft, however, communication between instructor and pupil was by means of a speaking tube. A growing volume of complaints about the speaking tube systems in the Wirraway and Tiger Moth brought this subject to the attention of the Acoustics Laboratory. R.A.A.F. authorities were concerned at the inefficiency of communication, which often became so poor as to jeopardise the safety of the aircraft. At least one fatal accident was thought to have occurred because the instructor could not at a critical moment communicate with his pupil. Diminution in efficiency of communication with time was at first attributed to fatigue in the listener caused by excessive noise, but later it was traced to strain on the instructor's voice from talking against the background of noise from the aircraft.

Laboratory tests on the speaking tube system of the aircraft revealed that with a standard noise level of 118 decibels only 15 per cent of a set of test words (Harvard word list Q.S.R.D. 383) could be clearly distinguished. Under similar conditions of noise and using the standard electrical intercommunication system of the R.A.A.F., 63 per cent of the words could be clearly heard. Owing to the general shortage of electrical equipment in Australia at the time it was necessary to retain the speaking tube system. But it was clear that it needed considerable improvement.

Detailed examination of the tube system by Mr Murray and Flight Lieutenant Pollard[5] revealed a number of factors responsible for its poor efficiency. To overcome these defects they designed a system incorporating ear-pieces and mouth-pieces in the form of folded or twisted exponential horns,[6] suitably shielded against external noise. These were mounted and connected into one piece. With this new system, under standard conditions of noise 95 per cent of the test words could be clearly identified. Its performance so impressed Lieut-Commander Humby of the Royal Navy that he had a similar system installed in Avengers and Barracudas as a standby in case of failure, either directly or through enemy attack, of the electrical intercommunication system.

Some noises, such as the blast from a large bomb, are so violent that they may cause death; others, less violent, such as those produced by gunfire, may cause temporary or permanent deafness. Once the difficulties

[5] N. E. Murray and F-Lt A. H. Pollard, "The Murray Speaking Tube System", Acoustic Research Laboratory Report No. 11. (F-Lt A. H. Pollard, BSc. Actuary; of Ashfield, NSW; b. Melbourne, 9 Aug 1916.)

[6] A flared horn the area of whose cross section increased exponentially; it was used in loudspeakers, gramophones, etc.

of intercommunication in aircraft and tanks had been overcome the Acoustic Research Laboratory turned its attention to the study of blast from guns then being built in Australia. Blast characteristics of the 25-pounder, the 3.7-inch anti-aircraft and anti-tank gun and other guns were studied in detail. The problem was to devise suitable ear plugs to protect the gun crew. It was essential to be certain of the efficacy of the plugs and to indicate precisely the circumstances in which their protection was necessary. These ear plugs gave protection against permanent deafness and also helped to make the gun crew more efficient by reducing the effects of temporary deafness. Men rendered temporarily deaf after a day's firing of the noisy short 25-pounder in New Guinea, were at a considerable disadvantage on sentry duty at night when trying to detect the approach of Japanese.

The effects of repeated attacks of temporary deafness caused by excessive noise were known to be cumulative and likely to lead to permanent deafness. Pilots of Catalina flying boats which often carried out lengthy reconnaissance flights of up to thirty hours' duration, were exposed to just such conditions. By means of ear plugs specially designed to equalise pressure as the aircraft changed altitude, crews of Catalinas were given protection against the danger of becoming permanently deaf. Ear plugs of this kind were made by boring a fine channel down the centre of the plug, which let in air but greatly reduced the noise.

Experience gained in these investigations was turned to good account after the war by supplying and maintaining hearing aids to ex-servicemen. Some of the most interesting work was that done on deaf-mute children, particularly those born to mothers who had contracted German measles during pregnancy in the epidemic that occurred in Australia in 1941.[7] When these children had been provided with suitable hearing aids, they could more easily be taught fluent speech. The necessity of placing them in institutions for the deaf and dumb could often be avoided, and they were able to lead more normal lives.

[7] Sir Norman Gregg, of Sydney, in 1941 discovered that children born in these circumstances frequently suffered from eye defects that resulted in blindness. This suggested to investigators the possibility of other sequelae, among which were found deafness and heart disease.

CHAPTER 22

METEOROLOGY

ONE account of the origin of weather forecasting traces it back to the Crimean War. After a particularly violent storm which did considerable damage to both the French and English fleets the Emperor Napoleon III commissioned the astronomer Le Verrier to organise a system of weather forecasting.[1] About the same time Admiral Fitzroy in England and Lieutenant Maury in the United States became interested in collecting, tabulating and discussing observations of weather and ocean currents for the benefit of shipping. Within a few years meteorological offices and networks of observing stations were set up in these and other countries and experiments in storm warning and weather forecasts were begun. Ever since, war has continued to influence the development of meteorology.

The war of 1914-18 was the first in which specialised meteorological information was extensively used. The scope of such information widened as the war progressed. At first the British Expeditionary Force in France was supplied with data from London. When this arrangement proved inadequate a "detachment" of two officers—one a meteorologist with the rank of captain and the other a professional assistant with the rank of lieutenant—was sent to France to set up the Meteorological Field Service. The service, which later became known as the Meteorological Section of the Royal Engineers, grew rapidly and by the end of the war numbered 28 officers and 187 other ranks.

Its principal functions were to forecast wind conditions for gas warfare, to give data on wind and clouds at flying levels for the Royal Flying Corps, and towards the end of the war to give information on wind and temperature up to the maximum height of trajectories of shells fired from guns and howitzers. A growing interest in the upper levels of the earth's atmosphere was a distinctive feature of meteorology at this period. For the previous half-century meteorology had been confined to the lowest level of the earth's atmosphere. These observations formed the basis of synoptic meteorology, which is essentially the construction and study of maps showing the results of simultaneous observations at different localities of barometric pressure, temperature, wind and other weather factors.[2]

It was by means of isobars drawn on weather maps that the pressure systems known as cyclones and anti-cyclones were first recognised. These systems and their associated weather elements show varying degrees of persistence and move with a velocity that can be determined from a series of maps constructed from observations made at stated times. Knowledge of the sequence in changes of the weather elements that accompany the

[1] S. Petterssen, *Introduction to Meteorology* (1941).

[2] The weather chart, which was first introduced by Brandes in 1820 (*Beitrage Zur Witterungs-Kunde Geschichte der Witterung des Jahre 1783*, Leipzig 1820), did not become important until methods of rapid communication enabling its prompt construction were introduced. The Meteorological Office in London began to collect reports by telegraph in 1861 and soon after issued forecasts in daily newspapers.

movement and variation of the pressure systems as disclosed by a series of weather maps formed the basis of weather forecasting.

It was, however, not possible to deduce, still less forecast, the conditions in the upper levels of the atmosphere from weather maps based only on surface observations. As an illustration of the inadequacy of the meteorological information available to Germany early in the 1914-18 war, one may cite the fate of the Zeppelins which set out to bomb London. Because of their crews' ignorance of the direction and strength of the winds blowing over England at the time of the raid, the Zeppelins failed to reach their target and dropped their bombs on east coast towns instead.

As a result of the remarkable growth of military aviation and the extensive use of artillery bombardment during the 1914-18 war, large numbers of observations on upper winds were made, both by pilot balloons and by meteorological flights by aircraft.

Another effect of the 1914-18 war was to seriously disorganise the collection of ground level observations from different European countries. In an effort to overcome these difficulties the Norwegians, instead of relying on simultaneous observations from widely-scattered centres, decided to use simultaneous observations made at a large number of very closely spaced centres in Norway. From weather maps of the relatively small area the meteorologists V. and J. Bjerknes (father and son) discovered what were called "polar fronts". In making this discovery they were considerably helped by the earlier work of two British meteorologists (Shaw and Lempfert) who had studied the life history of cyclones in great detail. The gist of the polar-front theory of the origin of cyclones was that they developed along the boundary of a cold, dry air mass from a polar continental region, and a moist, warm air mass from a tropical maritime region. The common boundary of two such air masses was termed a "front" by analogy with the line along which opposing armies faced each other in the first world war. From their wartime investigations the Bjerknes developed a method of using weather observations known as "frontal analysis", which was soon widely applied to weather forecasting in the Northern Hemisphere.

Meteorology, more than any other branch of science, depended on the existence of an efficient organisation for the collection of data, and for its work to be effective the area under study had to be as extensive as possible. It was considerations of this kind, no doubt, that led the framers of the Australian Constitution to make meteorology a Commonwealth responsibility. In January 1908 the Government established the Commonwealth Bureau of Meteorology with headquarters in Melbourne, and placed it under the direction of Mr Hunt,[3] who thus became the first Commonwealth Meteorologist.[4] At the same time a State division was set up in each capital city.

[3] H. A. Hunt, C'wealth Meteorologist 1908-31. Of Elsternwick, Vic; b. London, 7 Feb 1866. Died 7 Feb 1946.

[4] The first official weather observations in Australia were made at Hobart in 1841. On the mainland they began in 1856 with the appointment in N.S.W. and S.Aust of government astronomers, whose duties included the recording of meteorological data.

The bureau was made responsible for (*a*) synoptic meteorology, that is, the taking and recording of meteorological observations, the issue of weather forecasts and warnings of floods and storms; (*b*) climatology, which included the compilation of weather statistics and their application to primary and secondary industry. These activities engaged the attention of about twelve professional officers in the Central and State Bureaux. A small research section created in 1921 was placed in charge of Edward Kidson,[5] Assistant Commonwealth Meteorologist. Kidson, who had served in the Meteorological Section of the Royal Engineers in France and in Salonika, exercised an important influence on the development of Australian meteorology for the next few years. He introduced the techniques of observing upper winds which he had learned during the 1914-18 war; regular pilot balloon observations were begun in Melbourne in 1921.[6] Their extension to other centres was slow: regular observations were not made in Darwin until 1934, and an Australia-wide network of pilot-balloon stations was not organised until 1937. Pilot balloons at this period carried a device known as a "meteorograph", which made automatic records of temperature and humidity. The balloon in flight was observed by means of an automatic theodolite, and its direction and speed were calculated from these observations. The records of temperature and humidity, however, could not be examined until after the meteorograph had been recovered, and they were therefore not available as an immediate aid to forecasting. A more direct means of obtaining the same information was by the use of aircraft. In the early thirties the Research Section of the Central Bureau, then in charge of Mr Barkley,[7] collaborated with the R.A.A.F to make weather observations up to 16,000 feet. Temperatures and humidities were measured by means of instruments attached to the struts of the aircraft. The wealth of new observations in turn necessitated the introduction of modern meteorological methods for their treatment. A far-sighted, well-conceived plan to provide these services was authorised in 1937 at a conference between representatives of the Meteorological Bureau, Department of the Interior, and the Public Service Board. The execution of the plan in the next few years greatly strengthened and modernised the meteorological services.

Kidson also encouraged developmental work on the adaptation of the Norwegian frontal theory to the Australian and Southern Ocean region. This work was steadily pursued within the Research Section by Dr Treloar.[8] Frontal analysis was not used in published forecasts until 1936 and then only on the basis of observations that were not sufficiently numerous to permit the most effective use of them. Forecasters did, however, make

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[5] E. Kidson, OBE; DSc. (Capt RE 1915-19.) Director, NZ Meteorological Services, 1927-39. B. Bilston, Staffs, Eng, 12 Mar 1882. Died 12 Jun 1939.

[6] Upper air observations of temperature and wind in Australia were first carried out experimentally in 1913 by Griffith Taylor who used a balloon meteorograph designed by W. H. Dines of the British Meteorological Office.

[7] H. Barkley. Officer-in-charge, research section Central Meteorological Bureau, 1927-31; Assistant C'wealth Meteorologist 1931-38. B. Melbourne, 7 Oct 1883. Died Jul 1938.

[8] W Cdr H. M. Treloar, DSc, LLB. Meteorologist; of Melbourne; b. Adelaide, 20 Jul 1898.

considerable use of the new upper-air temperature and humidity observations.

In the early years of the bureau's history the network of observing stations was very sparse, and to offset this as much as possible attention was concentrated on maintaining a high standard of accuracy in the observations and records of weather. Over the years the density of the network within the Commonwealth was gradually increased and its range extended to the mandated territories.

By 1939 a vast amount of observational data had been accumulated, analysed and published and many investigations had been undertaken in synoptic meteorology and climatology, all of which provided the basic information for operations in the war years. This work was accomplished by meteorologists who received their specialised training and experience in the bureau. Their number was far too small to warrant setting up a special training organisation. The universities gave some courses in meteorology though not to the extent needed for training professional meteorologists. At the University of Sydney for example, a course of meteorology and climatology was instituted in the Department of Geography in the early thirties. Important researches on the climatology of Australia had been made by the department's first professor of geography, Griffith Taylor.[9] No Australian university had on its staff a full-time lecturer in meteorology until the University of Melbourne in 1939 created a Department of Meteorology which it placed in charge of Dr Loewe.[10]

The rapid growth of civil aviation in Australia during the late thirties made heavy demands on the meteorological services. More extensive observations of upper winds and air temperatures, more frequent surface observations and additional details such as visibility and height of cloud ceiling were now required.

Meteorological offices were set up at each of the major aerodromes: Karumba, Townsville and Archerfield in Queensland; Mascot, Canberra, Essendon and Parafield; Western Junction in Tasmania; Maylands in Western Australia and at Port Moresby. Observer stations were manned at a number of other aerodromes to attend to pilot balloons and meteorological observations.

The plotting and analysis of weather reports in a meteorological office required a team of forecasters and assistants working in continuous shifts, and observers to carry out regular weather and pilot balloon observations and plot the result on working charts. The weather officer then located the "fronts", drew in isobars, studied clouds, rainfall, winds and wind changes, and finally forecast the condition to be expected along the air route or at the destination of the aircraft. In this way pilots could expect

[9] T. Griffith Taylor, BA, DSc, BE. Associate Professor of Geography, Univ of Sydney, 1920-28; Prof of Geography, Univ of Chicago, 1929-34, Univ of Toronto 1935-51. B. Walthamstow, Eng, 1 Dec 1880.

[10] F. Loewe, PhD. Senior Lecturer in Meteorology, Univ of Melb. Of Melbourne; b. Berlin, 11 Mar 1895.

to obtain a comprehensive picture of the weather conditions likely to be experienced throughout their flight.

The assumption of these responsibilities by the bureau meant that new staffs had to be recruited and trained as quickly as possible. Courses of instruction in all sections of meteorology, including air mass frontal analysis, were drawn up by Treloar and put into operation with the help of his colleagues in the Research Section (Messrs Hogan[1] and Cornish[2]) and of Dr Loewe. The foundation courses thus laid down were later extended by Messrs Dwyer[3] and Forder[4] to include the analysis of upper air maps and tropical forecasting, a subject that was to become a constant preoccupation of many meteorologists in the South-West Pacific theatre of war.

To carry forward the reorganisation of the greatly enlarged Meteorological Bureau so that it could cope with the immediate and pressing requirements of civil aviation and the possible emergency of war, the Public Service Board in July 1938 appointed Mr Warren,[5] one of its ablest organisers and administrators, to the post of Assistant Director (Administration). Warren was not a trained meteorologist. It was nevertheless largely due to his administrative drive and skill that the 1937 plan was successfully completed and Australian meteorology was so well prepared to meet the demands of war.

One of his first actions was to implement the projected expansion of the organisation's work by increasing the frequency with which observations were made. Up to this time observations for synoptic purposes had been made only twice a day—at 9 a.m. and 3 p.m.; from 1st April 1939 seven daily observations were made, at 3-hourly intervals, at each of about ninety observing stations throughout the Commonwealth. All observations were coded and transmitted by teleprinter to the central office where they were plotted on maps. To organise the telegraphic transmission of these reports was in itself a major undertaking. Added to this was the considerable labour entailed in the construction of seven daily weather maps. These, however, greatly facilitated analysis of the weather by ensuring greater continuity of information. The formation of the civil aviation weather services before war broke out was a fortunate circumstance indeed since it provided a firm foundation for their extension to meet the requirements of the R.A.A.F.

In July 1939 when war appeared imminent, a conference was held between representatives of the navy, army and air force and executives of the Commonwealth Bureau of Meteorology to consider in broad outline

[1] Sqn Ldr J. Hogan, BSc; 252498. Officer-in-Charge of Research and Training Section, Directorate of Meteorological Services, RAAF. Of Melbourne; b. Geelong, Vic, 23 Nov 1896.

[2] Sqn Ldr A. W. Cornish, BSc. Meteorological Services, RAAF, 1941-45. Of Melbourne; b. 11 Nov 1910.

[3] W Cdr L. J. Dwyer, BSc. Director of Meteorology, Dept of Interior, since 1955. Of Hawthorn East, Vic; b. Geelong, Vic, 1 Dec 1907.

[4] Sqn Ldr D. H. Forder, BA, BSc. Chief Instructor, RAAF Meteorological Services 1943-45. Science master; of Riverton, SA; b. Caltowie, SA, 9 Sep 1912.

[5] Gp Capt H. N. Warren. Dir, Allied Meteorological Services, SWPA, 1942-46. Of Melbourne; b. Melbourne, 6 Apr 1888. Died 5 Aug 1950.

the meteorological requirements of the Services. From the discussion it was evident that the requirements of the R.A.A.F. so overshadowed those of the other Services that the conference decided to recommend to the Federal Cabinet that in the event of war the meteorological organisation should be transferred to the Department of Air as a directorate of the R.A.A.F. This transfer was effected on 1st July 1940, purely on a civilian basis; the bureau did not at this stage become part of the R.A.A.F.

In the interval between the outbreak of war and the transfer Warren had not allowed the bureau to mark time; practically all its major activities, such as training, weather analysis and studies in climatology (especially of the tropical islands to the North of Australia) were intensified and accelerated. Numbers of science teachers were recruited from State education departments to augment a forecasting staff that was ultimately to serve in all parts of the South-West Pacific Area, ranging over some 15,000,000 square miles. From this time onwards instruction became one of the main preoccupations of the bureau and continued so until the end of the war. At some periods of the war demands for meteorologists and observers were so great that it was only with the greatest difficulty that they could be met.

As it became more difficult to import instruments, the small section which had been set up within the bureau in 1938 to repair, maintain and calibrate meteorological instruments, was given the task of preparing specifications for their manufacture in Australia. This section later became a most important centre for testing and checking a wide range of Australian-made aircraft instruments.

The final step in the transformation of the Commonwealth Meteorological Bureau to the R.A.A.F. Directorate of Meteorological Services was completed in April 1941. Members of the bureau who had volunteered and were medically fit were enlisted for service with the new directorate and given rank appropriate to their positions in the bureau. Warren was appointed Director with the rank of group captain. Treloar became Assistant Director (Technical) with the rank of wing commander. The Divisional Meteorologists for New South Wales and Queensland (Mares[6] and Richards[7]) became wing commanders, and those in other States and heads of sections at headquarters were accorded the rank of squadron leader. Even though it had become part of the R.A.A.F., the Meteorological Directorate continued to serve the needs of the army and navy, and of the civil community. For security reasons, however, it ceased to publish forecasts for civilian purposes. After being taken over by the R.A.A.F. the meteorological service grew to about five times its peacetime strength.

Field activities of the directorate developed rapidly, both on the Australian continent and in outlying islands. R.A.A.F. meteorological stations had been established at Richmond and Rathmines in New South Wales,

[6] W Cdr J. D. Mares. Divisional Meteorologist, NSW, 1918-44. Of Avoca Beach, NSW; b. Sydney, 30 Jan 1879. Died 11 Aug 1952.

[7] W Cdr A. S. Richards. Deputy Director, C'wealth Meteorological Services, Qld. Of Brisbane; b. Beechworth, Vic, 22 Dec 1886.

Laverton in Victoria, Pearce in Western Australia, and Darwin in the Northern Territory. These were followed in the winter of 1941 by others at advanced operational bases in the Pacific: at Tulagi (Solomon Islands), Vila (New Hebrides) and Noumea (New Caledonia); later in that year stations were set up at Koepang (Timor), and at Ambon and Namlea.[8] At the same time fully-equipped meteorological units were attached to air force stations in Malaya to serve R.A.A.F. squadrons located there. An Area Meteorological Office was established in the R.A.A.F. Northern Area at Townsville.

These extensions involved the organisation of networks of radio communication. Differences of language, of codes and of practices in the meteorological services of the South-West Pacific and South-East Asian regions caused considerable confusion and made some attempt at standardisation imperative. A combined Communications and Meteorological Conference at which Australia, Great Britain, the United States, New Zealand, the Netherlands East Indies and the Federated Malay States were represented, was held at Batavia on 17th July 1941. The outcome of the conference was that a uniform series of meteorological codes and cyphers was agreed upon, the preparation of which was delegated to the Australian Meteorological Services. A code system known as ANDUS (because it was for use by Australian, New Zealand, Dutch and United States forces) was worked out by Squadron Leader Camm[9] and W. S. Watt,[1] a former Commonwealth Meteorologist who had recently retired. This system, which enabled uniform meteorological data to be provided for all Allied services operating in the area irrespective of nationality or language, went into operation throughout the region on 15th November 1941, shortly before the Japanese attack on Pearl Harbour.

While these developments in the field were taking place important investigations on methods of forecasting were being pursued within the Research Section at headquarters. There, Mr Squires,[2] who had studied methods of weather analysis under Dr Treloar, was chosen to lead the new attack on the problem. Treloar had developed the application of frontal analysis to Australian conditions to the point where, beginning in 1938, it was used in issuing a daily statement to State offices for the purpose of assisting them in forecasting the local weather. It was now decided that the time had come to intensify work on frontal analysis by using the great wealth of data that became available after the extension of the number of daily observations. Treloar's earlier work had shown that although cold fronts played an important part in Australian weather the general pattern of the weather, especially in the sub-tropical regions, did not conform at all well with that experienced in Europe and North

[8] The officers in charge of these advanced bases were respectively: Sqn Ldrs J. L. Williams, B. Mason, C. J. Wiesner, B. Rofe, R. A. E. Holmes, G. W. Mackey (accompanied by A. K. Hannay and D. H. Forder), and A. C. White.

[9] W Cdr H. E. Camm. (Served 1st AIF.) Meteorological Services RAAF 1941-45. Meteorologist; of Melbourne; b. 24 Oct 1892.

[1] W. S. Watt, C'wealth Meteorologist to 1940. Of Melbourne; b. Green Island, NZ, 2 Jan 1876.

[2] Sqn Ldr P. Squires, BSc. Meteorologist, Weather Bureau, Melbourne; Directorate of Meteorological Services, RAAF, 1941-46. B. Melbourne, 12 Jul 1914.

America. One of the early difficulties met with in tracing fronts in the Australian region was due to the fact that the southern maritime air was rapidly modified as it passed over a warm land surface and it often became difficult to locate the front. This difficulty was further accentuated in the tropics where conditions were still more unfavourable for the maintenance of fronts.

Before proceeding further it may be helpful to digress for a moment to explain a little more fully what was meant by a "cold front". The atmosphere, especially where it is more or less stagnant, tends to assume the temperature of its underlying land or water surface. A widespread body of air which is reasonably uniform in temperature in its horizontal plane (that is, parallel to the earth's surface) is called an "air mass"—warm or cold according to the temperature of the surface which it over-

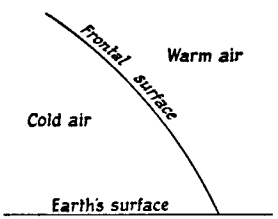


Fig 1. A vertical section through two air masses

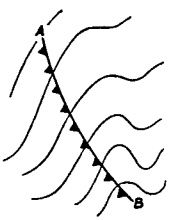


Fig 2. A "cold front" at ground level

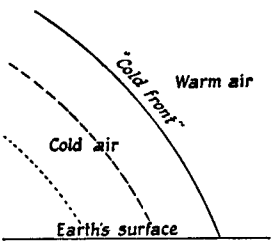


Fig 3. Successive positions of "cold front"

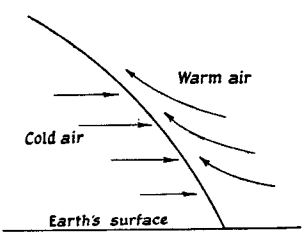


Fig 4. Air movement in a "cold front"

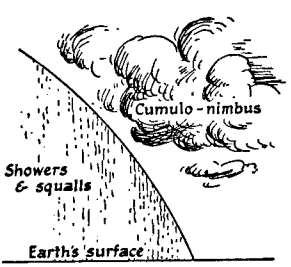


Fig 5. Clouds and weather in an active "cold front"

lies. For reasons which it is difficult to explain briefly, the boundary between two air masses in a cold front is nearly always a sloping surface, the warmer air overlying the colder. The slope of the surface over wide areas ranges up to 1 in 50. Seen sideways it would appear as shown in Fig. 1. In this idealised representation the curved boundary surface between the air masses cuts the earth's surface in a line AB (see Fig. 2) which was the conventional method of representing a cold front on a weather map.

If the movement of the air was such that cold air continually displaced warm air, the front was said to be a cold one. Because it is lighter, the warm air tends to ride up over the advancing wedge of cold air. On being

forced upwards the warm air cools and if it is not too dry the moisture in it condenses to form showers or thunder clouds of the cumulo-nimbus type, and rain may begin to fall.

Squires was faced with the arduous task of dealing with a mass of data pouring in daily from about 100 widely scattered observing stations. Each of the 700 or more reports consisted of about a dozen observations on cloud, rain, temperature, pressure, wind, humidity. All this information was incorporated on the seven daily synoptic weather charts. When confronted with the problem of handling large masses of numerical data the scientist can as a rule get help from calculating machines, but such machines were of little use in the present situation. There was no escaping the necessity of plotting all data on charts. Squires was confronted with the difficulty that by restricting himself to the methods found successful in the northern hemisphere it was not easy to spot fronts on weather charts of sub-tropical Australia. He found that the best method of locating cold fronts was not to concentrate on the variation from place to place of weather elements such as temperature, as was the usual practice, but to study the variation of these elements with time at any one place. If at a particular station one or more of these elements was found to behave in a manner which did not seem consistent with the normal daily trend, or could not be explained by local effects of topography, it could be suspected that a new air mass had arrived over the station. Naturally there were all sorts of extraneous factors to distract the forecaster. It might suddenly become cool at a coastal station merely because a sea breeze had arrived, and not because a cold front had brought in a new, colder air mass. But since fronts, being the boundaries between very extensive air masses, can move only in a fairly regular way, it was possible to piece together the evidence from neighbouring observing stations and successive synoptic charts, just as in some huge jig-saw puzzle.

As soon as these difficulties had been mastered arrangements were made for the widest possible dissemination of the results of frontal analysis. Beginning in January 1941 the Melbourne office sent out, once a day, a coded message to the State offices and also to all forecasting stations in the Commonwealth, delineating the positions of fronts and pressure systems. This was intended to assist local forecasters, being in the nature of a second opinion on the weather situation. Forecasters were still responsible for their own analysis of the weather, and for the forecasts which were based on it.

In 1942 the Japanese overran most of the advanced air stations that had been set up in 1941. Withdrawal from these stations was not without difficulties. Perhaps the most trying experiences were those endured by an R.A.A.F. party on Timor led by meteorologist Flight Lieutenant Rofe.[3] The party struck across the mountains to the south coast where they were to have been picked up on 10th February 1942. It was not until the

[3] Sqn Ldr B. Rofe, MBE. Directorate of Meteorological Services RAAF 1941-46. Of Norwood, SA; b. 14 Sep 1917.

middle of April that they were rescued by the American submarine *Sea Raven* after suffering severe hardships and the loss of four lives. Early in 1942 Port Moresby, Vila, Noumea and Willis Island were the only Allied observing stations in the Pacific Islands.[4]

While the American forces were stationed in Australia it was necessary to give the meteorological officers attached to the U.S.A.A.F. and U.S.N. weather services some opportunity to adapt themselves to Australian conditions. For a while the staffing and working of the Australian and American meteorological sections were combined as far as practicable to enable the latter to gain experience of local conditions. In June 1942 the Allied Air Meteorological Service was constituted by order of General Brett, commanding the Allied Air Forces, with Group Captain Warren as Director and Squadron Leader Timcke[5] as Assistant Director. Lieut-Colonel Twaddell, a meteorologist of the American Army Air Force, was Deputy Director. This association, which was of mutual benefit to Australian and American meteorologists, lasted until the end of the year when for tactical reasons the services were reorganised into separate Australian and American components.

As the Japanese advance was gradually stemmed and eventually rolled back, weather units of the Australian Directorate of Meteorological Services were once again established at advanced operational bases at Milne Bay, at Goodenough, Morotai and Labuan Islands, to mention only a few. Rather than attempt to follow the fortunes of individual meteorological units, a story which more properly belongs to other volumes, attention will be confined to the more general aspects of their work.

The weather intelligence required during the war fell into two main categories: climatological studies for long-range strategic planning, and short-range forecasts for military operations. For the purposes of long-range planning a Climatological Intelligence Section was created within the directorate and placed under Squadron Leader J. Hogan. The section obtained considerable help from studies begun shortly before the war under the direction of Mr Foley.[6] A critical examination was made of rainfall statistics for all the years of record in the New Guinea region, and these, together with climatic summaries of temperature and humidity for the same region, were published in 1940. Requests for climatological information began to come in to the Directorate of Meteorological Services from Allied Headquarters about the middle of 1942, the first being for information on Guadalcanal (in the Solomons) just before the United States forces began their drive there against the Japanese. From then until the end of the war the Services made numerous requests for climatic information for use in planning operations in New Britain, New Guinea and the Netherlands East Indies. Although climatic studies indicated in a general

[4] Moresby and Noumea continued to function uninterruptedly since the Japanese did not reach them. During 1942 the RAAF meteorological staff was withdrawn, but not because of Japanese activities.

[5] W Cdr E. W. Timcke, OBE; BA. (Served 1st AIF.) Deputy-Director, RAAF Meteorological Service, 1942-46. Of Melbourne; b. Payneham, SA, 2 Apr 1890.

[6] J. C. Foley, BSc. Chief Scientific Officer, C'wealth Meteorological Services, since 1948. Of Hobart and Melbourne; b. Broadford, Vic, 19 Jun 1892.

way the kind of weather that might be expected in a given locality at a particular time of the year, they could not take the place of short-term weather forecasts. They did however pave the way for forecasts.

Another valuable piece of work completed by the Climatological Intelligence Section about this time was the compilation of a handbook on the local weather over the ocean areas included in the Australia Naval Station, a region which included not only the Tasman Sea and Eastern Indian Ocean but also the waters of the eastern parts of the Netherlands East Indies and the Bismarck Archipelago. A request for such a handbook had been made to the Commonwealth Meteorological Service by the Admiralty late in 1939. It was planned as one of a series then being prepared by meteorological offices of the British Empire and designed to cover practically all the oceans. The area to be covered was so great that it was necessary to deal with it in twelve sections. It was a fortunate, but probably not entirely fortuitous circumstance, that the first area selected for treatment was the Pacific Ocean from the Territories of Papua and New Guinea through the Solomon Islands to New Caledonia. Being outside the area of likely naval operations, the zone from latitude 46 degrees south to the Antarctic Continent was the only one not completed during the war. Little was known about the meteorology of this area and after the war attempts were made to fill the gap by establishing meteorological stations at Heard and Macquarie Islands.

The essential task of a forecaster in planning a military operation was to predict the meteorological conditions at the time of the initial strike. So long as this information gave the commander an opportunity to complete the first blow under conditions favourable to himself, the forecaster's part was truly played. Limited as his role may appear to have been, it was not an easy one to play in the tropics, where the vagaries of the weather were less well understood than in almost any other part of the globe. This arose partly from the fact that it was intrinsically more difficult to understand the weather of the tropics and partly from the fact that since the more industrialised countries of the world lay outside the tropical zone, few meteorologists had paid much attention to it.

For a time there was also a scarcity of observations. As the Japanese approached the southernmost limits of their advance the network of tropical reporting stations was very severely reduced and most of the information required had to be collected by aircraft reconnaissance, by army spotters, and sometimes by intercepting Japanese reports and "breaking" their code. Later, when meteorologists were posted to tropical stations, they began to appreciate the problems of forecasting in this region. At first they held to methods to which they had been accustomed and sought to identify boundaries between "equatorial maritime" and "tropical maritime" air masses of either hemisphere. They were able to recognise that there was a line or zone of demarcation between air masses which had migrated from regions over the North Pacific or the Asiatic continent, and air masses of southern origin. This "line" was referred to at first

as the "inter-tropical front" and later as the "inter-tropical convergence zone". There appeared to be no well-defined front but rather a zone of convergence of the trade-wind or monsoon circulations of the northern and southern hemispheres. Early experience led forecasters to doubt the existence of fronts in low latitudes and they soon abandoned the method of frontal analysis in favour of a method of streamline analysis and the delineation of convergence zones with which clouds and bad flying weather were associated. With recognition of the fact that whatever detailed mechanisms were operating bands and areas of severe weather in the tropics move towards the equator in much the same way as fronts move in higher latitudes, some kind of forecasting became possible. The severity of the weather could be analysed by methods similar to those used in frontal analysis.

This degree of understanding was attained only after a concerted effort. When Allied Headquarters moved to Brisbane in 1942 a meteorological unit led by officers with experience of tropical weather—Flight Lieutenant Holmes[7] and Flight Lieutenant Gibbs[8]—was attached to it. These officers attended headquarters conferences in the operations room each day and gave a weather summary and forecast which was used to guide decisions affecting the movement of the forces. This unit became the Tropical Research Centre, and in 1943 it began the daily issue of a statement of the weather situation covering the Western Pacific from Northern Australia to Japan. The publication of a *Tropical Research Bulletin* to which a large number of meteorologists working in forward operational bases contributed, was instituted in 1944. The bulletin, which was edited by Gibbs, served as a medium not only for the exchange of ideas between tropical forecasters in the war zone, but also for conveying this knowledge to other parts of the world. The *Tropical Research Bulletin* was recognised by the Air Ministry in London as one of the "two most outstanding contributions to tropical meteorology up to this time".[9]

As the war progressed the amount and extent of information available to Australian meteorologists gradually increased, giving them a more and more detailed picture of the condition of the earth's atmosphere up to a height of ten miles. Two factors contributed to this. The first was the introduction in 1943 of the radio sonde, a device which had already been in use in other parts of the world for several years. The radio sonde consisted of a small balloon equipped with remarkably compact instruments for automatically recording temperature, pressure and humidity and simultaneously transmitting this information by radio signals to observers on the ground. Observations made by means of a network of radio sonde stations supplemented by a large volume of observations made from aircraft in flight, provided a wealth of fresh detail about the South-West

[7] Sqn Ldr R. A. E. Holmes. Directorate of Meteorological Services 1941-46. Meteorologist; of Claremont, WA; b. Perth, WA, 9 Mar 1915.

[8] Sqn Ldr W. J. Gibbs. Directorate of Meteorological Services 1941-46. Flight clerk, Qantas Empire Airways Ltd. Of Sydney; b. Kogarah, NSW, 31 Oct 1919.

[9] Air Ministry Report, Meteorological Research Committee, London, 30 Dec 1946.

Pacific Area. The first pressure charts for levels of 10,000 and 20,000 feet were drawn regularly at the Tropical Research Centre, and a daily statement of the pressure pattern at 10,000 feet was issued to forecasting stations. At a later date "constant-pressure" surfaces of 700 and 500 millibars were adopted in place of constant-level surfaces, and the contour lines of heights of constant pressure surfaces were drawn instead of isobars. Such charts were useful aids for forecasting winds for flying. After the war constant-pressure charts for these and still higher levels (300, 200 and 100 millibars) provided data which formed the basis for important new developments on the theory and practice of meteorology and an understanding of the general circulation of the atmosphere.

As the amount of meteorological information coming into the weather services from operational and other areas increased it became progressively more difficult to recruit enough trained men to handle it. In 1941 members of the Women's Auxiliary Australian Air Force were recruited for service in the meteorological headquarters and divisional weather bureaux as meteorological charters. The work of the first mustering was so satisfactory that women were employed extensively to replace men in operating teleprinters, coding, and other duties. Women were then trained as meteorological assistants, and finally, in 1942, women began to be employed as forecasters. The first WAAAF Weather Officer was Section Officer Burke[1] who was employed in the Forecasting Section Headquarters. She was joined in 1943 by Flight Officers Atherton,[2] Carnegie[3] and Scott.[4]

The provision of reliable forecasts for aircraft of the R.A.A.F. and Allied Services was undoubtedly the most onerous single task of the Directorate of Meteorological Services. Factors of importance in the conduct of air operations were a knowledge of winds for navigation, of visibility and cloud cover for air strikes and landings and for parachuting troops and supplies, and a knowledge of turbulence, icing and other conditions that might endanger the safety of an aircraft. On the Kokoda Trail, for example, considerable use was made of the knowledge of weather conditions in dropping supplies to Australian troops.

Predictions of cloud cover to enable supplies to be dropped by American Transport Squadrons and by Hudsons and former civil aircraft operated by the R.A.A.F., were made by local forecasters. Many other similar examples could be given to show how successfully the meteorological services operated. The Chief of the Air Staff, Air Vice-Marshal Jones,[5] in

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[1] F-O Elizabeth F. Burke, BA, MSc. Economic Research Officer, Bank of NSW; Air Force HQ 1941-44; Meteorological duties RAAF Station, Richmond, NSW, 1944. Of Sydney; b. Mittagong, NSW.

[2] F-O Kathleen G. Atherton, BA. Cypher duties 1941-43; Directorate of Meteorological Services RAAF 1943-46. School teacher; of Brisbane; b. Atherton, Qld.

[3] F-O Agnes L. Carnegie, BA. Air Force HQ 1941-42; Directorate of Meteorological Services RAAF 1942-46. School teacher; of Brisbane; b. Brisbane.

[4] F-O Doris E. Scott, BSc. Administrative duties 1942-43; Directorate of Meteorological Services RAAF 1943-45. School teacher; of Brisbane; b. Gympie, Qld.

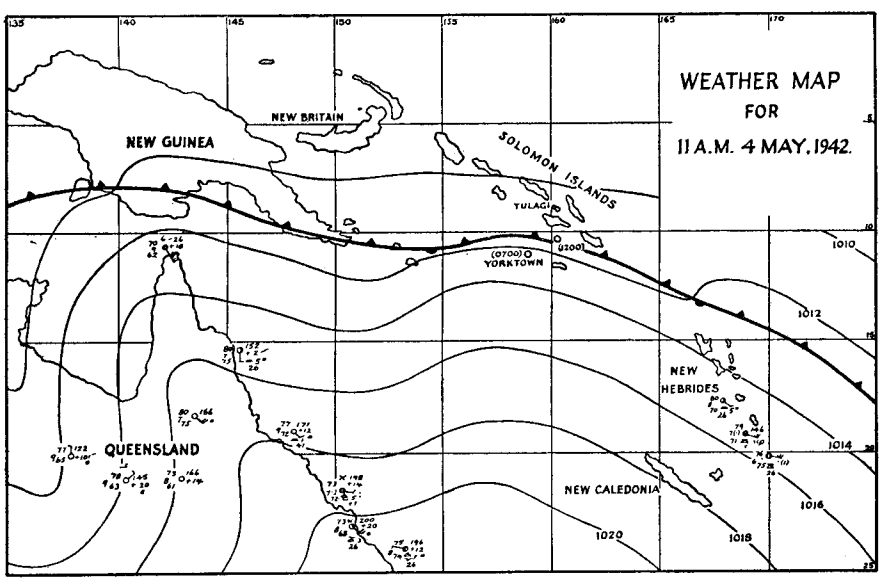
[5] Air Marshal Sir George Jones, KBE, CB, DFC. (Served 1st AIF.) Dir of Training RAAF 1940-42; Chief of Air Staff RAAF 1942-52. Of Melbourne; b. Rushworth, Vic, 11 Nov 1896.

his War Report paid this tribute to his Meteorological Service: "It earned and retained the confidence of Allied Operational Commanders and associated weather organisations."

Advice for the navy comprised regular reports and forecasts of weather in its area of operations. These were supplemented by detailed information on coastal areas. For these areas forecasts of wind, weather, cloud, visibility, state of sea and swell were provided at 6-hourly intervals. From July 1941 special weather reports and analyses of wind speeds were provided for minesweeping. Cyclone warnings were also broadcast for the Queensland coast during the hurricane season.

An illustration of the extent to which weather could affect the course of a naval-air engagement is afforded by the Battle of the Coral Sea in May 1942.[6] The Japanese began the action early on the 3rd May by occupying Tulagi in fine weather with their main carrier force covering them from the north.

Informed by air reconnaissance of the invasion of Tulagi, Admiral Fletcher in the carrier *Yorktown* swung northwards towards the Solomons



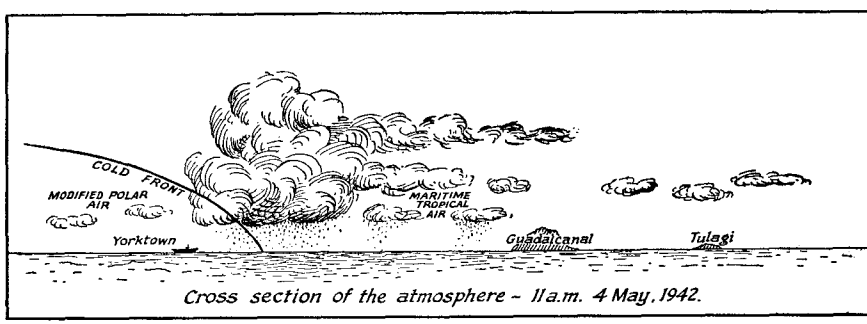
under the cover afforded by a "cold front" moving up from the south. By 4th May the zone of bad weather, with its showers and squalls and low visibility, lay in an east-west direction just south of Guadalcanal. While still in this frontal zone the *Yorktown* launched its first attack. Heavy cloud provided excellent concealment for the aircraft for almost the whole of their journey until they broke into clear weather just before reaching

[6] In the Coral Sea the weather is dominated by the semi-permanent high pressure area of the Southern Hemisphere and although south-easterly monsoon winds are constant for a greater part of the year this circulation is occasionally affected by the passage of a cold front off the Australian continent.

their targets. In this action they succeeded in damaging the Japanese destroyer *Kikuzuki,* which later sank.

The Japanese fleet intended for the second operation, the invasion of Port Moresby, sailed from Rabaul late on 4th May, screened near New Guinea by the light carrier *Shoho* and farther east by two heavy carriers, *Zuikaku* and *Shokaku,* with their attendant cruisers and destroyers. Three days later, from under the cover of the frontal system which now lay across the Coral Sea between 10 and 15 degrees south, the carriers *Lexington* and *Yorktown* struck. In the mistaken belief that the *Shoho* was the main force, the Americans concentrated their attack on this ship and sank it. Meanwhile the Japanese reconnaissance aircraft, having missed the two American carriers still hidden in the bad weather, chanced upon the fleet tanker *Neosho* and its attendant destroyer *Sims,* much farther to the south. This time the Japanese made the mistake in identification, and believing the tanker to be a carrier pressed home the attack, sank the destroyer and damaged the tanker, which sank later.

The Port Moresby fleet was recalled to Rabaul on the morning of 7th May and began steaming northwards while the *Australia* (flying the flag



Cross section of the atmosphere - 11a.m. 4 May, 1942.

of Rear-Admiral Crace[7]), the *Chicago* and the *Hobart* were moving towards it. The *Lexington* and the *Yorktown* had left the frontal zone and in perfect weather steamed close to the Japanese carriers during the night of 7th-8th May. By now the weather favoured the Japanese carriers, which lay hidden in the belt of bad weather. Next morning both sides launched their strikes simultaneously. The Americans had difficulty in finding the Japanese carriers because of the cloud blanket. The only part of the force that attacked did so through a slight break in the overcast. At this juncture one of the Japanese carriers, *Zuikaku,* dashed into a rain squall and disappeared in a region of poor visibility, but the other, *Shokaku,* not so fortunate in its manoeuvres, was struck by bombs and put out of action for several months. The Japanese aircraft, however, approached the United States carriers in bright sunlight and converging on the *Lexington* scored hits with bombs and torpedoes, so damaging it that it sank later in the

[7] Admiral Sir John Crace, KBE, CB; RN. Served as torpedo officer in HMAS *Australia* and HMS *Hood* in first world war; commanded Aust Squadron (and Task Force 44) 1939-42; Admiral Superintendent HM Dockyard, Chatham, 1942-46. B. Canberra, 6 Feb 1887.

day after an internal explosion. Without a single shot having been exchanged by surface vessels, both sides now withdrew.

After the war had spread to the Pacific the army shared in the directorate's general meteorological services, such as were provided in forecasts issued twice daily to the War Room in Melbourne and in Sydney. As a means of ensuring that the army's more specific needs were supplied, Squadron Leader L. J. Dwyer was attached to Army Headquarters as Meteorological Liaison Officer. He arranged for the anti-aircraft defence officers to be supplied with the data on wind and temperature needed for ballistic corrections; for the issue of statements concerning conditions of flight to the Army Carrier Pigeon Unit; for the issue of advice to Lines of Communication showing areas where storms, floods, bush fires and other conditions dangerous to troop movements or military operations could be expected.

One of the most important services organised by Dwyer for the army was the Mobile Meteorological Flight Service, consisting of six units, each of which comprised a forecaster and four observers and was attached to corps or division headquarters, usually under a commander of artillery. These units saw even more front line action than the weather sections attached to the R.A.A.F.: they gave advice on meteorological conditions for the use of smoke screens, the dropping of paratroops and supplies; they made forecasts of surf and tides at beach-heads, of conditions of sea for army small craft, and of visibility for close artillery support of infantry; they also assisted in field experiments conducted by chemical warfare units in Queensland. But their most important function was to make observations on the strength and direction of wind for the purpose of calculating corrections to be applied to gunfire. This they did by observing the flight of pilot balloons. The Mobile Meteorological units were the first to employ radar in Australia for observing pilot balloons at night or through obscuring cloud.

When it became necessary to bring a barrage down to within 50 or 80 yards of our own troops, meteorologists were often hard put to it to keep up a sufficiently rapid flow of observations. Firing in the jungle at night to prevent infiltration by the Japanese was often greatly assisted by a knowledge of wind velocity. It was possible for the artillery to direct their fire to a particular zone without "ranging" shots, and so to surprise the enemy.

For long-range firing the ballistic correction was sometimes astonishingly high. For example, in March 1945 a detachment from No. 3 Meteorological Flight in action with the 2/2nd Australian Field Regiment at Matapau, west of Aitape, calculated a range correction of 1,025 yards for a battery firing a supercharge from the Anumb River to the outer defence of But with our own troops disposed less than 300 yards from the target area. This correction was something of a record, and its application in the circumstances indicated great confidence in the work of the meteorologists.

Just as chemists and engineers examined captured equipment in order to assess the enemy's strength, so meteorologists attempted to assess the skill with which he made use of the weather. Some meteorologists believed that in the second world war Japan made more operational use of the weather than any other nation. They considered that as early as November 1940, Japan demonstrated her competent use of the weather factor in timing the landing at Hanchow Bay; and that the same nicety of timing was shown at Milne Bay (24th August to 8th September 1942), the Buna-Gona landing (22nd November 1942), and in fact throughout the Japanese advance in the South-West Pacific. In general the Japanese forces moved in under a protective cover of cloud and rain.

In May 1943 the British Air Ministry decided that it was vital to maintain an Empire air link with Australia and New Zealand. Part of the route was from Perth to Colombo, the longest single hop in the world until the use of the Cocos Islands made a midway stop practicable. The problem of forecasting for the route was a difficult one, involving as it did an investigation and prediction of air circulations in two hemispheres over a distance of about 3,000 miles. Assistance in this task was obtained from regular reports from the observing station set up by the R.A.A.F. in the Cocos Islands and also from weather reports from Ceylon. Even so the meteorologists did not have a great deal of information to work on. The first flight was made on 12th May 1943 to a forecast made by Flight Lieutenant J. Hogan[8] (not to be confused with the Squadron Leader J. Hogan mentioned earlier) who had gained his knowledge of tropical meteorology from three years' service as a meteorologist at Port Moresby. In all, more than 1,000 air-transport crossings between Ceylon and Australia were made up to 1946 without the loss of a single aircraft. Similarly wartime experience gained in forecasting for the region between Sydney and Suva greatly increased the safety of air travel between these two capitals.

Several not very well understood phenomena which were of interest to the Services were investigated by meteorologists. One example of particular interest to the air force, namely "precipitation static", was studied in detail by Treloar. When an aircraft flew through certain types of cloud it became electrically charged and consequently a source of radio waves. These waves, which constituted "precipitation static", seriously interfered with the reception of radio signals from the aircraft. Treloar identified the kinds of cloud most likely to cause precipitation static. With the aid of accurate descriptions of these clouds and the circumstances under which they were likely to be encountered, pilots were able to mitigate the trouble from precipitation static simply by avoiding flying through such clouds.

A problem of great interest to the Services when planning landing operations was that of forecasting the height of sea waves for periods

[8] Sqn Ldr J. Hogan, BSc; 292527. In charge New Guinea Meteorological Services, Pt Moresby, 1938-40, Indian Ocean Forecasting Section RAAF, 1943-46. Deputy Director Meteorological Services, SA, since 1953. Of Perth, WA; b. Boulder City, WA, 29 Feb 1912.

ranging from a few hours to a few days ahead. A method for doing this had been evolved in the United Kingdom but it had not been put to the test in the South-West Pacific Area. Using observations made on the Tasman Sea, Treloar verified the practical utility of the method, and it was extensively used throughout the Pacific.

While planning their bombing operations in New Guinea in 1942 American Headquarters was greatly interested in the upper winds over the area. In response to their request Treloar prepared an account of winds up to 30,000 feet for the whole of the area stretching from New Guinea to Singapore.[9]

Activities in sections at the central bureau and in the State divisional bureaux followed much the same pattern as they did in peace time. Although censorship imposed a restriction on the customary methods of publishing weather reports, all the normal activities associated with preparing these reports went on as usual. The Climatological Section at headquarters gave advice to agriculturalists concerned with the introduction of flax in Victoria and with the growing of vegetables and other foodstuffs for the armed forces. At the end of the war a series of climatic surveys was instituted as part of the war service land settlement scheme.

As had been originally planned, the Directorate of Meteorological Services was transferred after the war to the Department of the Interior, which was entrusted with its reorganisation on a civilian basis. Re-formation of the civilian organisation was not without its difficulties. Despite the fact that the numbers of technical and trained men in the meteorological services had increased five-fold during the war, there were not enough to man the post-war civil organisation. There were two main reasons for this. Firstly the majority of the wartime new-comers were "duration personnel" who returned to their former civil occupations on being demobilised. Secondly the post-war meteorological and climatological requirements of the defence services, civil aviation, and primary and secondary industry, greatly exceeded the demands of the pre-war era. To take but a single instance: before the war aviation services had been confined more or less to the daylight hours; now they were maintained practically throughout the 24 hours. This and the expansion of oversea services necessitated larger meteorological staffs at the aerodromes. Only after an intensive recruitment campaign was the Commonwealth Public Service able to build the meteorological services up to the required strength.

Australian meteorology emerged from the war modernised and strengthened. New techniques had been discovered and elaborated; valuable equipment had been acquired, and meteorology had been firmly established as a science. Great strides had been made in the meteorology of Northern Australia and the adjacent tropical regions. Developments which in peace time would have come only after many years' work and a constant struggle for financial support, were compressed into a few years. It was now possible for the Commonwealth Weather Bureau to give efficient

[9] For these and other investigations the University of Melbourne awarded Treloar a DSc degree—the first in Australia for meteorological work.

service to the internal airlines of Australia and adjacent territories, and also for international flights into the northern hemisphere.

It was no reflection on the fine record of the wartime meteorological services that the New South Wales Branch of the Institute of Physics in its report on "The Place of Physics in Post War Australia" should have deplored the disproportionately small amount of fundamental research in meteorology achieved in Australia. The amount was small in comparison with what might be expected of a country whose prosperity is so intimately associated with weather, and it was small in comparison with what remained to be done. The physical processes of the atmosphere are so complex that hardly more than a beginning has been made towards understanding them. Until they are better understood little hope can be held out for revolutionary improvements in forecasting. In 1955 the period covered by a forecast in Australia was still about what it was before the war (a matter of about 48 hours at most) and the same held good for most other parts of the world. The problem of long-range forecasting, the successful solution of which might permit steps being taken to alleviate some of the disastrous effects of floods and droughts, still eluded the meteorologists.

The post-war period saw a number of interesting developments in meteorological research. No attempt was made to set up a single central research organisation such as was advocated by the Institute of Physics. Instead, existing centres were strengthened and others were added. Two important sections were set up within the Council for Scientific and Industrial Research: a section of Meteorological Physics in Melbourne under Dr Priestley[1] (set up in 1946), and a section in the council's Radiophysics Division, whose main preoccupation was the study of the physics of cloud and rain formation, a field of investigation in which Australia rapidly assumed a leading role. The advantages of cooperation between centres of meteorological research were not overlooked. The Department of Meteorology of Melbourne University and the Research Section of the Bureau of Meteorology joined forces to undertake a long-range study of seasonal forecasting.

[1] C. H. B. Priestley, MA, DSc. Meteorology Office, British Air Ministry, 1938-46; Chief of Section (now Division) of Meteorological Physics, CSIRO, since 1946. B. Highgate, Eng, 8 Jul 1915.

CHAPTER 23

CAMOUFLAGE, CIVIL DEFENCE AND MAPPING

AS early as March 1939 each State had assumed responsibility for the detailed planning of measures for the protection of civil populations from enemy attack. As was more or less inevitable in the absence of a common plan, divergences in organisation and in the nature of the measures adopted soon developed. This condition of affairs was allowed to persist until about the middle of 1941 when the imminence of war in the Pacific gave a sense of greater urgency and compelled the Government to place civil defence on a national basis. This it did by setting up in July 1941 the Department of Home Security. The work of two sections created within the new department, namely the Research and Experiments Section and the Camouflage Section, falls within the scope of this volume.

The Research and Experiments Section, comprising a small group of full-time scientific officers in charge of Mr Vincent,[1] was constituted to handle the problems associated with protecting the population against air raids.[2] With the help of advisory committees drawn from other scientific organisations, and with the cooperation of the Australian Scientific Research Liaison Offices in London and Washington, it covered a wide range of scientific and technical problems. Structural engineers were called in to advise on the design of air-raid shelters, on the treatment of shatterable materials such as glass and asbestos cement, and on the strengthening of existing buildings. Physicists were consulted about the effects of bomb blast and problems of controlling lighting during the dimming and blacking out of cities. Chemists cooperated in training air raid wardens in methods of detecting and counteracting poison gases; they also studied new types of incendiary agent introduced by the Japanese and advised on methods of counteracting their effects. Physiologists investigated the efficiency of the methods used for ventilating air-raid shelters; botanists investigated the efficacy of methods for protecting timbers used in air-raid shelters against the destructive attacks of insects and fungi; and bacteriologists gave advice on the best ways of disinfecting respirators. This by no means exhausts the list of the activities of the Research and Experiments Section of the Department of Home Security but it is a representative cross-section of them.

The department's second scientific section, that of Camouflage under Professor Dakin,[3] grew out of activities which began long before July 1941 and whose influence went beyond civil defence.

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[1] J. M. Vincent, DScAgr. Lecturer in Agriculture, Univ of Sydney, 1939-55; Scientific Officer, Dept of Home Security 1941-43; Assoc Prof Microbiology, Univ of Sydney, since 1955. B. Narrabri, NSW, 14 Aug 1911.

[2] J. M. Vincent, "Science in Civil Defence", *Australian Journal of Science*, Vol. 6 (1944), p. 117.

[3] W. J. Dakin, DSc. Prof of Zoology, Univ of Sydney, 1928-49; Technical Director of Camouflage 1941-44. B. Liverpool, Eng, 23 Apr 1883. Died 2 Mar 1950.

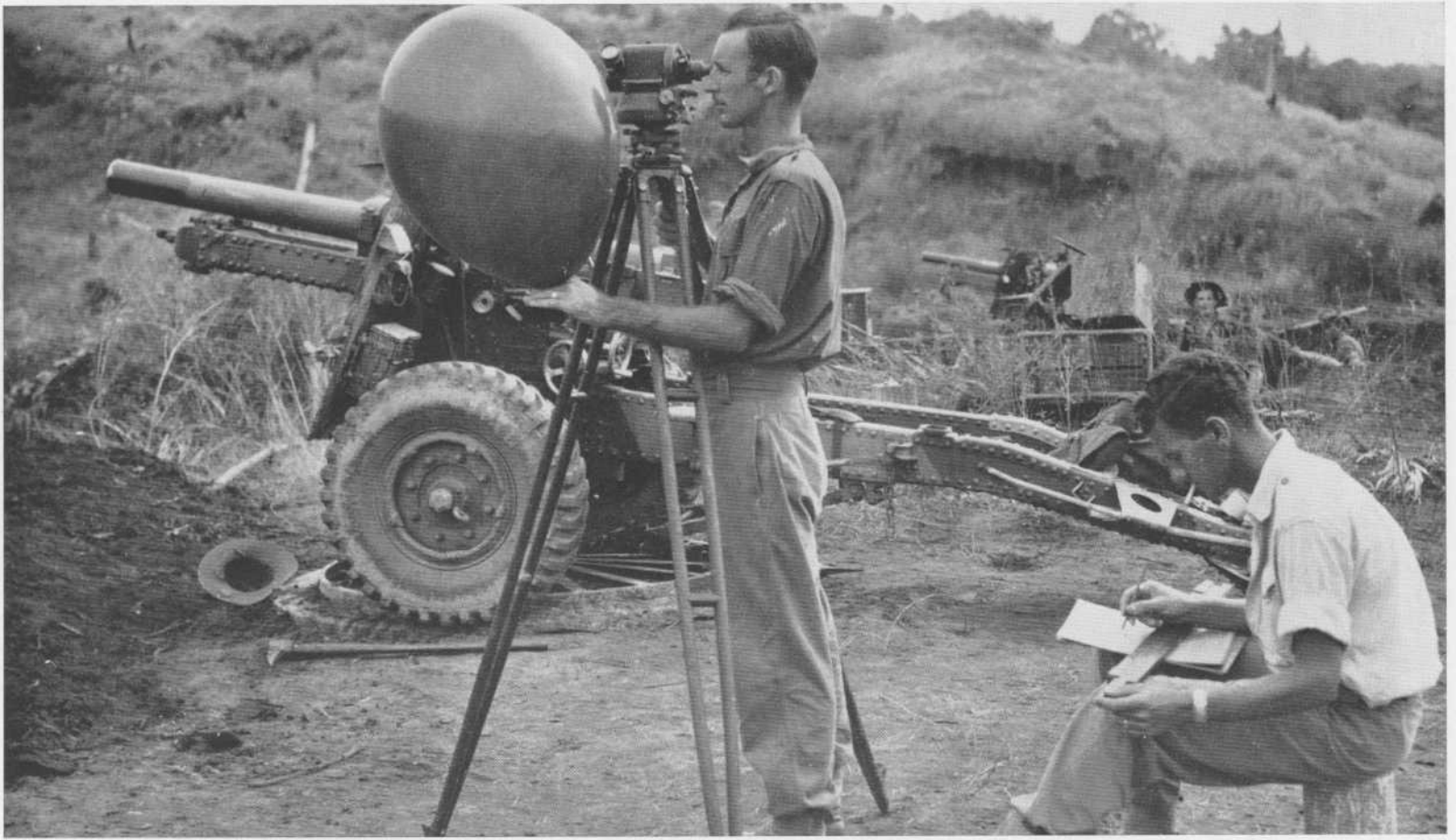
The use of artifices to deceive or surprise an enemy is probably as old as warfare itself, but the first organisation to work out scientifically based principles of concealment was instituted by the French in the war of 1914-18. It was then that the practice of using tricks to conceal any object completely from the naked eye, or to conceal an object by making it look like something entirely different, came to be known as camouflage. At first much effort was directed to concealing objects from observation at ground level, but with the advent of the aeroplane as an instrument of war the art of concealment assumed a new importance and entered a stage where it had to contend with detection by photography and the air observer.

Although there were great developments in aeronautics in the inter-war period, the study of camouflage, in England and the United States at all events, did not appear to keep pace with these changes. Little attention was paid to static camouflage[4] in Australia until about 1938, when the Defence Committee asked the Services and Munitions Supply Board to consider and report on measures for the protection by camouflage of important defence factories. Up to that time there had been no establishment for investigating the technical problems of camouflage, or for producing the special materials needed for camouflage. Early in 1939, acting on advice from the Defence Committee, the Prime Minister asked the Naval, Military and Air Boards to submit reports on the steps being taken to provide camouflage protection of their respective establishments. Since it was beyond doubt that any future war would be fought in the air as much as on land and sea, it was obvious that in addition to purely military objectives important civil establishments would also need camouflage protection. The subject was therefore likely to be of interest to civilians and to members of the Services alike.

A short time before the outbreak of war a group of citizens, comprising engineers, architects, artists and several members of the Services, got together under the leadership of Professor Dakin to consider the principles and problems of camouflage.[5] As a zoologist Dakin had long been interested in animal colouration, concealment and vision, and he was moreover familiar with the part played by camouflage in the war of 1914-18. A man of great energy and infectious enthusiasm, Dakin soon succeeded, through the contacts made by the army officer members of the Sydney Camouflage Group, in bringing its work under the notice of the Department of the Army, which at this time (1939) was not greatly impressed with the need for the costly static camouflage of civilian installations. Undaunted by the official attitude, the Sydney group investigated schemes for camouflaging important water, gas and oil installations and aerodromes in and around the Sydney area.

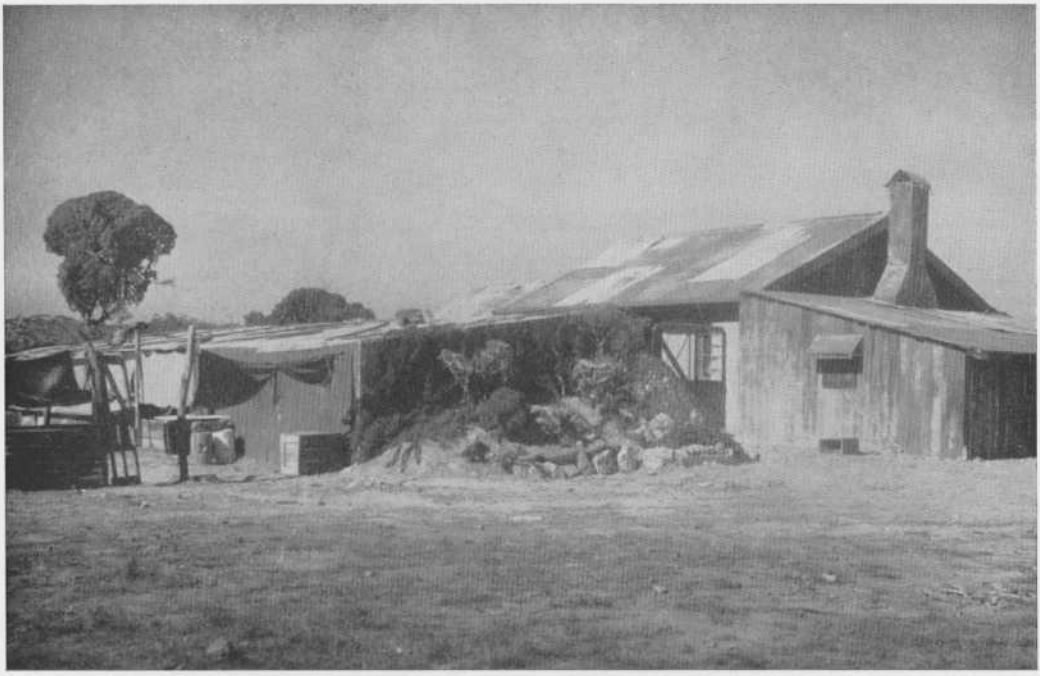
[4] Camouflage may be classified roughly as follows: (i) static camouflage, as of aerodromes, factories and fortifications; (ii) field camouflage—in fighting zones; (iii) operational (strategic or offensive camouflage).

[5] Members of the Sydney Camouflage Group, which was entirely unofficial and voluntary, were: Prof W. J. Dakin (Chairman), Mr V. F. Tadgell (Hon Sec), Prof L. Wilkinson, Sydney Ure Smith, Frank Hinder, R. Emerson Curtis, Russell Roberts, P. Dodd and Douglas Annand, Col D. A. Whitehead, Capt B. F. Hussey, Gp Capt H. F. de la Rue and John D. Moore.

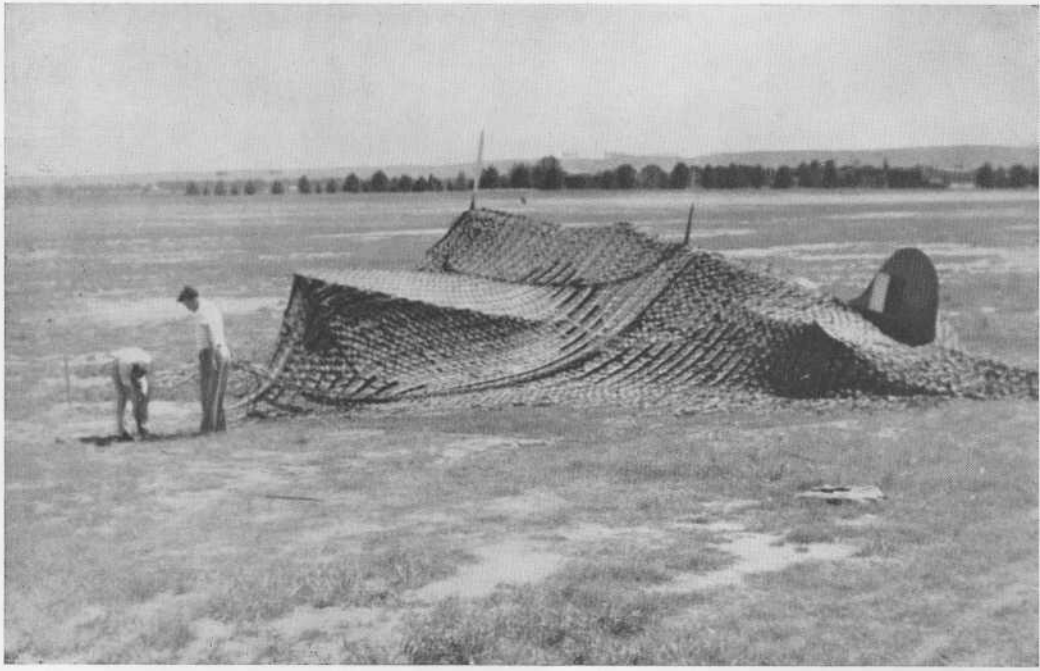


(*Australian War Memorial*)

Members of the 3rd Australian Mobile Meteorological Flight attached to the 6th Australian Division computing ballistic wind for artillery cooperation. Variations of humidity, temperature and wind in the upper air were of vital importance in artillery fire. Standing: WO C. J. Paddick. Sitting: Sgt R. R. Rankin. Photograph taken in the Wewak area, N.G., June 1945.



Magazine at Bankstown, New South Wales, camouflaged by surrounding with cheap iron, etc., to make a disreputable hovel.



(*Prof W. J. Dakin*)

Covering of aircraft almost completed.

Though this work was without official recognition and laboured under the consequent disadvantages, no effort was spared to bring it to the notice of appropriate authorities. It was first officially recognised in August 1940 when the Defence Committee urged that plans should be made for camouflaging establishments of national and military importance, and recommended that some organisation should be set up for this purpose. Accordingly a meeting of representatives of the Services, the Department of Defence Coordination, Departments of Interior and of Munitions, together with civilians from New South Wales and Victoria,[6] which was held on 8th and 13th November 1940 at Victoria Barracks, recommended the formation of a body to be known as the Defence Central Camouflage Committee. In the most general terms, it was to be responsible for development, control and coordination of all matters of camouflage—both Service and civilian, within the Commonwealth, and for advice, if called upon to give it, on matters of camouflage affecting the Australian Imperial Force. Subject to the Defence Committee, technical approval of all schemes of camouflage was to rest with the Defence Central Camouflage Committee.

A sum of £5,000 was recommended for the setting up of a camouflage workshop and research station at George's Heights, Sydney. Subsidiary to the central camouflage body there were to be State Camouflage Committees whose duty it was, among other things, to furnish technical advice and to supervise camouflage schemes for establishments within the States.

The recommendations were duly agreed to by the War Cabinet on 9th April 1941, and the Camouflage Committee met for the first time on 2nd May 1941. At this meeting Dakin, in recognition of his earlier activity and great interest in the subject of camouflage, was appointed to the post of Technical Director of Camouflage.

The responsibilities of the Camouflage Committee were more specifically defined under the National Security (Camouflage) Regulations in August 1941 at the time of its incorporation in the Department of Home Security. They were

(i) to prepare lists of places of national and military importance which in the opinion of the committee should be camouflaged;

(ii) to conduct experimental work in relation to camouflage and types of defence and civil camouflage equipment;

(iii) to prepare and approve plans for camouflage schemes and to coordinate and control all such schemes;

(iv) to maintain records of all available information relating to camouflage;

(v) to coordinate and direct the activities of State Defence Camouflage Committees; and

(vi) to advise the Minister (for Home Security) concerning any matters referred by him to the Committee.

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[6] Those present were: Cdr A. R. B. Phelp, RN (Dept of Navy); Lt-Cdr G. A. Gould, RAN (Dept of Navy); Lt-Col J. J. L. McCall, General Staff AHQ (Dept of Army); Maj T. H. B. Foott (Dept of Army); Sqn Ldr W. L. Hely (Dept of Air); W Cdr A. Hepburn (Director of Works); R. M. Baxter (Dept of Interior); J. R. Cochrane (Dept of Munitions); Lt-Col R. M. W. Thirkell (Director of Civilian Defence and State Coordination, Dept of Defence Coordination); Prof W. J. Dakin (Chairman Sydney Camouflage Committee); V. F. Tadgell (Secretary, Sydney Camouflage Committee); Daryl Lindsay (Curator of Art Museum and Keeper of Prints); D. J. Mahony (Director, National Museum, Melbourne).

No camouflage could be carried out without the permission of the Government, but the Government could order it to be carried out where it was advised to be necessary.

The need for an official controlling and coordinating body had been clearly demonstrated by experience in Britain where early in the war a good deal of valuable material and energy had been wasted in unnecessary camouflage. In both Britain and Australia the need for civil camouflage was small compared with the requirements of the Services. The Civil Camouflage Assessment Committee in Britain, for example, in a review of 2,500 individual civil establishments where it was thought camouflage would be in the interest of national defence, decided that by reason of the local topography, camouflage would be practically useless in 70 per cent of the cases.[7] No similar figures were ever published for this country but it is reasonable to expect that the proportions would have been much the same.

One of Dakin's activities during the months preceding the establishment of the Camouflage Committee was to write a small book, *The Art of Camouflage*. The general principles of camouflage are relatively few in number and easy to grasp, though perhaps not always so easy to apply. They have been discovered mainly from the study of the often remarkable colourings and shapes assumed by living creatures, as a result of ages of evolutionary modification, to enable them to escape destruction by their enemies. Most readily understood among the principles of concealment is the one which states that the colouring of an object should resemble that of its background. A moth with markings and colouring to match the bark of the tree upon which it rests is a manifestation of this principle, which found application in practically all camouflage work.

An opaque body may stand out from its background by reason of its colour, the texture of its surface, its contour and the form and intensity of its shadows; even though its colour blends with its background, it may yet stand out against it if illuminated from above, when the dark shadows of its under surface contrast with the light of its upper surface. Many animals, fishes and birds with a dark back and lighter coloured belly exemplify this principle, known as counter-shading. Not much use was made of it in military camouflage for its effectiveness depended on horizontal, or at most oblique, observation.

A pattern of contrasted colours and, or, tones could be arranged so that the surface of an object was broken up and the eye distracted by patches of colour and, or, tones having no relation to the shape of the object disguised. This principle was known as disruptive patterning. The popular conception of camouflage as the art of daubing an object with random patches of colour arose from the widespread application of this principle. However, any kind of patchy colouration was not necessarily camouflage. There was more to it than might appear at first sight and a good deal of

[7] W Cdr T. R. Cave-Brown-Cave, *Proceedings Royal Society of Arts*, Vol 93 (1945), p. 262.

poor camouflage in Australia resulted from a failure to appreciate fully the nature of disruptive patterning.

Lastly, there was the problem of avoiding shadows, an objective usually attained by the intelligent use of netting.

These, briefly stated, were some of the basic principles of concealment. Their successful application in war called for the services of many different kinds of expert—physicists, chemists, geologists, architects, artists, zoologists and engineers—and herein lay one of the difficulties of building up a camouflage organisation.

The Camouflage Research Station at George's Heights, Sydney, was completed and ready for work by the middle of 1941. There experiments were carried out on such subjects as the permanence of paints and dyes, the fire-proofing of camouflage materials, and on quick-growing plants for covering new earthworks and buildings. Camouflage was both an art and a branch of applied science. The discovery and elaboration of techniques of camouflage were scientific matters which called for men with a scientific background. The preparation and execution of schemes of camouflage, on the other hand, were matters requiring visual training and a knowledge of design, and thus called for architects, artists, engineers and town planners. Men with both kinds of qualification were required and in fact well represented among the Deputy Directors of Camouflage.[8]

Additional staff, in New South Wales for instance, was recruited largely by chance. A number of men, chiefly commercial artists and photographers, were appointed in December 1941 by the Department of the Interior as camouflage workers. After they had been given courses of instruction at George's Heights they were sent to aerodromes where in a very practical fashion they learned a good deal about the execution of camouflage schemes. From there they were recruited to the Department of Home Security and graded as senior camoufleurs or camoufleurs grade I, II, or III, according to their qualifications and experience.

Successful camouflage required not only trained men but special materials, the chief of which were netting (string and wire), paint of all kinds, and materials for garnishing netting, such as hessian and wool. Realising that there would be some difficulty in providing netting, because it was all imported, Dakin had quite early taken steps to meet possible emergencies by obtaining instructions from Lowestoft, England, where some years earlier he had seen fishing nets being made, and having women students of the Zoology Department at the University of Sydney taught the art of netmaking. In an emergency these women could, he believed, teach others. Fishing nets were not machine-made anywhere and unless their making were well organised it would be a long time before requirements could be met.

As in the war of 1914-18, netting was used to support the garnishing which played a great part in camouflage, and also as a screening curtain.

[8] The Deputy Directors of Camouflage for the various States were: NSW, John D. Moore, architect and artist; Vic, V. E. Greenhalgh, artist; SA, Louis McCubbin, Director of National Art Gallery, SA; Qld, R. A. McInnes, town planner and architect; WA, Prof A. D. Ross, scientist; Tas, Dr J. Pearson, Director of the Tasmanian Museum and Art Gallery.

Netting alone was usually not sufficiently opaque for camouflage; opacity was produced by garnishing the netting with materials whose surface matched the background in colour and tone. When used as an overhead cover, netting suitably disposed and garnished could also be used to make shadows less obvious. The first nets were used for experiments and demonstrations, and a few were given to army officers leaving for the Middle East.

Towards the end of 1940, after a lecture had been given by Dakin to officers of the 8th Division, stationed at Rosebery, near Sydney, the advantages of taking away supplies of camouflage netting began to be appreciated. When it had been explained to Major-General Gordon Bennett[9] that if the army could provide money for the string, nets could be made in large numbers, he saw to it that ample funds were provided.

With two lecturers from the Zoology Department acting as instructors, the training of members of the Women's Defence League began in earnest. Much credit is due to Miss Kay McDowell, who so ably organised the work of the league. Mainly through the publicity given by women's journals, voluntary netmaking extended all over Australia and was undertaken not only by women but also by men from such organisations as golf clubs and police associations.

Some time later Major Young,[1] G.S.O. III Camouflage Eastern Command, following the lead given by the civil organisations, organised a team of voluntary workers, mostly women, to garnish nets and wire netting for anti-aircraft and coastal defences. Much of this work was carried out on the actual sites and was efficiently and enthusiastically done. Similar teams of voluntary civilians were later employed in other centres not only for garnishing but for preparing special types of garnish, such as metal garnish made from the waste cuttings of tin manufacturers.

The cheapest material for weaving into netting was hessian, and the demand for it was therefore heavy. Although supplies had been frozen in 1940 because the hemp and jute from which it was made were not grown in Australia and it was needed for wheat sacks and wool bales, the great reduction in the export of wheat and wool that occurred during the early years of the war had enabled private firms to build up stocks of hessian, and these were diverted to camouflage.

One of the first problems in using hessian for camouflage was to find a method of colouring it suitably and permanently. At first it was cut by hand into strips 2 to 3 inches wide and then dyed by dipping it (again by hand) into a vat. Experience showed that costly camouflage works lost their effectiveness with alarming rapidity—within a few weeks—because of the fading of dyed hessian and other materials. The bright sunshine and high temperatures of the more northerly regions of Australia caused a far more rapid deterioration of camouflage materials than was experienced in Britain, for example. In fact the success of camouflage was

[9] Lt-Gen H. Gordon Bennett, CB, CMG, DSO, VD. (1st AIF: CO 6 Bn 1915-16; comd 3 Inf Bde 1916-19.) Commanded 8th Division in Malaya 1940-42; GOC III Aust Army Corps, 1942-44. Company director and orchardist. B. Balwyn, Vic, 16 Apr 1887.

[1] Maj W. A. Young. GSO III att to Staff of Cmd Camflg Offr, E Commd, 1941-43; DCRE 46 Aust DCRE (Wks) 1943-45. Engineer; of Auburn, NSW; b. Sydney, 13 Jan 1896.

so seriously threatened at one stage by the failure of materials that it became necessary to revise completely the specifications of camouflage materials.

A Camouflage Paint Committee was set up and meetings were arranged with the Paint Manufacturers' Association for the purpose of devising systems of paint testing. Until controlled tests on the performance of paints had been made it was difficult to pinpoint the causes of failure, which were mainly due to the instability of colour. It was found that to obtain stable colours the pigment must be almost wholly free of extenders. For covering fibro cement, paints of the pigmented alkyd-resin emulsion and oleo-resin emulsion types were found most suitable. A similar type of emulsion paint so thinned as to reverse the emulsion to one of oil in water, was found to be flexible and to have a particular affinity for jute fibres, and was therefore especially suitable for painting hessian.

Owing to the development (in Europe and the United States) of infra-red-sensitive photographic emulsions for aerial reconnaissance work, it was imperative that green pigments should have infra-red reflecting characteristics similar to those of vegetation. Whereas greens made from prussian blues failed badly in this respect, some of the natural greens—cobalt green, viridian and chromic oxide—were most successful. The high cost of several blue pigments that were suitable and available for the manufacture of satisfactory greens prevented their widespread use.

Having discovered suitable paints the next problem was to find a method of applying them to the hessian, which arrived in Australia in the form of rolls 6 feet wide and 5 miles long. One of the most notable achievements of the Camouflage Section of the Department of Home Security lay in solving this problem, with the collaboration of Michael Nairn and Co (Aust) Pty Ltd, Sydney (a linoleum manufacturing firm). This firm had a battery of seven ovens unique in Australia: each was over 100 feet long and 60 feet high and capable of drying 50 miles of hessian in one loading. The hessian was fed into a machine which applied the paint and then squeezed out the excess by means of rollers, in such a way that a specified weight of paint per unit area was obtained. From this machine the hessian was fed into the drying ovens where it was festooned in long drapes and allowed to dry for 24 hours or more. In the final step, the wide rolls were cut into 2½-inch strips by a special machine consisting of a series of rotary knives capable of cutting 100 square yards a minute.

Other camouflage materials were devised. Linoflage, for example, was a better quality hessian of the kind used for linoleum, which had been impregnated with a fire retardant chemical and then painted on both sides with specially prepared paints. In strip form it was used for garnishing; uncut it was used for making dummy buildings.

Another innovation achieved by Messrs Michael Nairn and Company was the construction of a machine to convert a continuous sheet of material into a net. Sheets of painted hessian, linoflage or "camsheen" were slit by rotary knives to give slots 6 inches long, spaced at 2-inch intervals and

staggered in rows. Sapper Boyle's[2] invention of a machine to garnish wire netting is described in the chapter on Inventions.

During the early part of 1941 the Camouflage Committee worked out schemes (often based on models) for the camouflage of some sixty different establishments. By about the middle of the year Rear-Admiral Muirhead-Gould[3] had succeeded in persuading the Government to make funds available for camouflaging the naval magazines and oil tanks at Chowder Bay and Garden Island, Sydney. This work, carried out by the Department of the Interior to plans drawn up by officers of the New South Wales Camouflage Committee, was the first large-scale camouflage project undertaken in Australia. Before the end of the year the R.A.A.F. aerodromes at Bankstown and Richmond, New South Wales, were fully camouflaged so that they could be used for demonstration purposes.

With the entry of Japan into the war the question of camouflaging civil establishments became a matter of some urgency.

Using the authority granted by the War Cabinet on 17th November 1941,[4] the Minister for Home Security on 12th December 1941 ordered the dull painting in one colour of all bulk oil tanks which had been previously listed as needing camouflage. The decision to apply only one dull colour was made by Dakin after considerable experiment and observation. Time after time it was seen that disruptive patterns and other supposedly effective camouflage paint treatments did not in fact conceal more completely but rather tended to advertise the fact that an attempt at concealment was being made.

In order to coordinate camouflage work, conferences of the chairmen of the State camouflage committees were called from time to time. The first was held in Canberra on 10th January 1942 to discuss the problem of appeasing the more fearful members of the public who were clamouring for camouflage in the belief that it was a complete safeguard against air attack. Dakin warned State chairmen against all but the most needful action and the following were granted first priority: petrol tanks, water-supply buildings; munitions works; gas works; electricity undertakings; white-roofed buildings in areas associated with defence works; food stores; special transport points and all pointers to important and vulnerable objectives.

About a year before Japan entered the war, the Director-General of Engineer Services asked for advice concerning the camouflage of Larrakeyah Barracks at Darwin, whose shining roofs could be seen from the air at a distance of 50 miles. In the course of discussion it was decided that camouflage of establishments at Darwin would be unusually difficult

[2] Spr R. S. Boyle, Aust Army Ordnance Corps. Carpenter; of Moonee Ponds, Vic; b. Mysia, Vic, 27 Jun 1906.

[3] Rear-Adm G. C. Muirhead-Gould, DSC; RN. Officer-in-charge Sydney Naval Establishments 1940-44. B. London, 29 May 1889. Died 26 Jun 1945.

[4] Minute 1507: *Financial Responsibility for Camouflage at Non Service Establishments.* The Minister for Home Security was empowered to bargain with occupiers of buildings selected for camouflage to determine the proportion of cost to be borne by the occupier and by the Commonwealth Government respectively.

and probably futile, because Japanese pearl-divers were already well acquainted with the area. Several months later the army revived the subject and invited the cooperation of the Camouflage Committee. Detailed maps and aerial photographs of the district were provided and from these the committee made models of a number of objectives and drew up an elaborate scheme of camouflage. The Department of the Interior sent 23 workmen and a cargo of materials to Darwin on the *Zealandia,* to carry out this scheme. The work had hardly begun when Darwin had its first and heaviest raid, during which the *Zealandia* was sunk, with the bulk of the camouflage material still on board.

In the confusion that followed little thought was given to camouflage for a month or so, but the lesson of what could happen without command of the air was plain enough. It was impossible to say just what effect this lack of preparation had on the severity of the Japanese attacks on Darwin, but it was realised that even adequate camouflage would have been only a small part of its defence.

This conclusion was reinforced a few weeks later when large numbers of seasoned and experienced troops returned from the Middle East. Officers of the returning army were impressed with some of the elaborate efforts at camouflage they saw in South Australia, but with vivid memories of much-bombed cities in the Middle East where the presence or absence of camouflage seemed to have made little difference to the degree of devastation, they thought such efforts were out of proportion to the needs of the situation. Dakin, resenting the opposition of the newly returned army leaders to many of the camouflage schemes, became critical of their judgment in these matters, and pointed out that the lessons of concealment learned in the Middle East were not always relevant to Australian conditions.

The inevitable clash between army and civilian authorities came not over the question of who had the more experience but over the question of who should control camouflage activities. The army's real concern was with what it believed in the circumstances to be a serious waste of manpower on unnecessary camouflage schemes. This concern is reflected in the following instructions issued by the Deputy Chief of the General Staff to all commands:

ENGINEER POLICY—FIRST THINGS FIRST

It should be recognised that the Japanese expect AUSTRALIA to fall into their hands as readily as previous countries, and that therefore, until our resistance warrants it, they will not attack anything that may be of use to themselves, but will concentrate on the destruction of our Field Armies and anything that these Armies are immediately dependent upon.

In an effort to settle what was clearly a fundamental difference in policy the Department of Home Security on 7th July 1942 arranged a conference between the Secretary of the department, the Engineer-in-Chief, the Technical Director of Camouflage, and the Secretary, Department of the Army.[5]

[5] Mr A. W. Welch, Maj-Gen C. S. Steele, Prof W. J. Dakin and Mr F. R. Sinclair respectively.

The conference decided that the powers granted by clause 5c of the National Security (Camouflage) Regulations, whereby the Camouflage Committee was "to prepare or approve plans for camouflage schemes and to coordinate and control all such schemes", were too extensive to be acceptable to an army in the field. Two amendments were therefore proposed, and were approved by the War Cabinet in October 1942, which would restrain the committee from interfering with Service action on camouflage. The effect of these instructions was to make the Camouflage Section of the Department of Home Security a purely advisory body to the Services and to leave with it the responsibility for civil defence and for conducting investigations on the development of materials and schemes for camouflage. Each Service now assumed control over its policy on camouflage.

While making instructional films to demonstrate the principles of field-craft and individual concealment, the Department of Home Security made many experiments to discover the best colour for uniforms in the jungle. The uniform first suggested was patterned in two or more shades—that is, the principle of disruptive colouring was used—but as a result of strong resistance by clothing manufacturers, and of experiments which showed that this type of uniform had very little in its favour, the army adopted "jungle green". The first troops to wear jungle greens went into New Guinea in September 1942. The original jungle green was a most uncertain colour and varied even in the one garment. Material from a dozen different rolls which originally looked exactly alike would come from the dyeing vat in as many different shades. The army, however, managed to insist that each shirt should come from one roll of material only, though this involved a certain amount of waste cutting. Such uniformity of shade was not really necessary for camouflage in the jungle, but it did appeal to the men, who objected to looking like harlequins when they went on leave.

The deception scheme employed by Australian troops on Goodenough Island affords an interesting example of the use of strategic or offensive camouflage. While the Buna-Gona operations were in progress it was feared that the enemy might land in force on Goodenough Island. A small Australian unit, having overcome a Japanese occupying force, was then holding the island. To hold it against an attack in strength would have required a brigade group, but since no such body was then available it was decided to camouflage the island so that it would look as though a brigade was occupying it. A scheme was evolved for dummying all the equipment of a brigade group: vehicles, tanks, weapons, tents, and even flashes, smoke, fires and dumps.[6] Signals traffic to the island was increased and Japanese intelligence was permitted to "discover" that a movement of troops was intended. Entering into the spirit of the scheme, and displaying

[6] The scheme was carried out with the advice of Capt R. L. H. Hall and was under the supervision of Lt W. B. King, officer commanding the New Guinea Forces Camouflage Training Unit. I am indebted to Capt K. H. McConnel, RAE, for these details.

great keenness and ingenuity, the men achieved a most realistic deception in which no detail was overlooked. The island was eventually fully occupied by Australian troops and became a base for air operations.

For a long time it had been known that the pink or light brown of a European skin stands out with striking clarity against green foliage. This fact was brought home with great force to the Australian troops as they fell back on Port Moresby early in September 1942. During that month the Army Inventions Directorate received an urgent request for a non-toxic green dye suitable for camouflaging the skin. After a hurried consultation with experts of Imperial Chemical Industries of Australia and New Zealand Ltd, the dye lissamine green (B.T.R.) was quickly tried and found suitable. At first it was supplied in the form of a powder, but as it was a very expensive material this wasteful method of using it was later superseded by one in which it was mixed with starch and magnesium stearate and made up into tablets. Curiously enough, men in forward areas were disinclined to make use of this aid to concealment, one reason being that they felt that the bearded and dirty faces of those who had been trekking through the jungle for days offered just as good a means of escaping detection. In much the same spirit as they used mosquito repellant for hair brilliantine, the men found in the dissolved green tablets a ready-to-hand ink for writing their letters home.

A more effective contribution to camouflage was a contrivance known as a "spider", a light-weight collapsible machine-gun cover of wire-rod construction over which a camouflage net could be draped. This invention, made by Frank Hinder,[7] proved so successful that it was adopted by the army.

Once the army had decided to go its own way, the Department of Home Security soon found that its camouflage activities were mainly confined to the R.A.A.F., for after October 1942, when the threat of Japanese invasion had disappeared, all civil camouflage was discontinued. Since the R.A.A.F. had no camouflage organisation of its own, men recruited from the groups of volunteer camoufleurs in Sydney and Melbourne were attached to it as civilian field officers.

When the army took over the Camouflage Research Station at George's Heights, the Department of Home Security began courses for R.A.A.F. officers at the University of Sydney, using rooms and equipment there for lecture purposes and taking the men out to Bankstown and other nearby aerodromes for practical demonstrations. The courses began on 18th July 1942 and ceased on 23rd May 1944; some fifteen classes were held, at which between 400 and 500 officers attended.

One of the difficulties experienced by officers of the Department of Home Security who were sent to operational areas at the request of the R.A.A.F. was their lack of a uniform, which they needed not for camouflage but

[7] Lt F. H. C. Hinder. Artist; of Wollstonecraft, NSW; b. Summer Hill, NSW, 26 Jun 1906.

to identify them and their purpose. Officers on R.A.A.F. aerodromes were not always willing to cooperate with civilians, who in any event were there only as advisers. At first the camouflage officers had no official status whatever. In order to obviate these difficulties warrant cards were issued, but camouflage officers still felt themselves in an anomalous posiiton. Uniforms were eventually provided without badges of rank, on the understanding that the Department of Home Security supplied its own marks and buttons. From all accounts this was not considered a satisfactory arrangement.

By far the greater part of the efforts of the Home Security camouflage section for the R.A.A.F. was directed to camouflage of airfields and ancillary installations. Although full information on British practice of camouflaging airfields was available to the R.A.A.F., some of the methods found to be effective there were impracticable in Australia because of the vastly different countryside. In Britain, where airfields were often situated in farmland, it was not difficult to make one look like the small cultivated patchwork of surrounding country. It was quite another matter with airfields cut out of the Australian bush, as many of the newer air strips were. The wide dispersal of airfields over Australia and the difficulty of reaching many of them by ordinary means of transport, offered problems very different from those of Britain.

At Dakin's suggestion the Chief of Air Staff agreed in October 1942 to the formation of the Aerodrome Camouflage Committee so that the problems peculiar to this type of camouflage might receive special attention. The most successful effort to "dull tone" runways was achieved at Williamtown where they were top dressed with crushed green slag (furnace slag). This method was however not widely used. A good deal of effort was concentrated on dispersed aircraft, magazines, petrol stores and any specially important buildings. The idea behind this was that if an objective could be sufficiently well concealed to delay recognition by the raiding bombers until fighters and anti-aircraft guns could get into action, defence might be made a little easier. Even though runways and taxiways were often pointers to the hideouts, concealment of aircraft did prevent the discovery by aerial reconnaissance of the number and types of planes at an airfield. A screened dispersal point might be occupied or not; it might even be a dummy. The aim of camouflage was not always complete concealment—deception was just as important.

At one period large numbers of aircraft were being lost on the ground. For this reason greater attention was paid to concealment of aircraft. Dull painting or disrupting patterns on a plane's surface did not always provide very helpful camouflage. A better method was to screen the plane by garnished netting, usually supported above the aircraft by wires slung from trees or posts. Special care was needed with the garnishing, particularly to see that the net was not uniformly garnished to its edges. The intention was that the centre of the net should be more or less opaque while the margin areas should allow the background to show through so that the whole net melted into the background.

Dakin treated the problems of airfield camouflage in great detail in a publication entitled *Aerodrome Camouflage,* which was of considerable help to those concerned with this problem. No attempt will be made to describe the wealth of information contained in this document but its preface is worth quoting, if only to show Dakin's approach to his subject.

> Camouflage in war is a duty and responsibility in which everyone in the Services may play a part. It is not a cloak solely developed for the protection of the weak. The tiger is protectively coloured. Offensive action needs concealment both for its preparation and consummation.[8] Camouflage has become a recognised device in modern war. It ranges from the large scale costly devices used to conceal very valuable property to the simple discipline for the concealment of the individual. One man with a tractor or a few men with their own feet may spoil the finest large-scale concealment work. It is the business therefore of all members of the unit, and a duty for all officers, even though they take no more active part in it than a recognition of the necessity for camouflage discipline and camouflage maintenance. The greatest necessity in the Air Services is the recognition of the fact that camouflage is not a means which, coming in at the end, can conceal badly constructed ground work and badly planned aerodromes.
>
> The camouflage requirements of any project must be realised and considered at the beginning. Until this becomes a natural procedure, camouflage will be both inefficient and costly.

Among the effective devices used by the R.A.A.F. were decoys. Three-ply imitations of Kittyhawks (P-40's) and cheap "flat" Wirraways, along with gun pits, small shacks and trucks, were used in the Darwin area. There is some evidence that the flat decoys about which considerable arguments raged were attacked by the Japanese, sometimes so successfully that army personnel in nearby areas broke up the dummies at night to prevent further attention by the enemy.

The difficulty about decoys was that, when they were favoured, which was not often, the Services usually wanted something which was complete in itself and required neither skill nor labour to set it up, and which yet had no weight and occupied no space in transport. The nearest approach to this somewhat exacting requirement was discovered overseas, in the form of inflatable rubber decoys, but it was impossible to import them and their manufacture in Australia was out of the question, if for no other reason than the shortage of rubber.

The Japanese temperament was such as to favour the use of decoys, and they achieved success and some subtlety at times. On one occasion, for example, they set up seven decoy planes so crudely that American airmen laughed at them and left them alone, only to discover later that the dummies covered stockpiles of materials.[9]

Camouflage of radar stations received a good deal of attention because many of them were isolated and had little protection other than conceal-

[8] A superb example of offensive camouflage was described by Churchill in his address to the House of Commons (11 Nov 1942) on the battle of Alamein. "By a marvellous system of camouflage a complete tactical surprise was achieved in the desert. The Germans knew an attack was about to be launched, but where, when or how was completely hidden from them. The 10th Armoured Corps which German reconnaissance planes had spotted fifty miles in the rear moved silently elsewhere in the night. In its place it left an exact duplicate of its tanks and other equipment."

[9] Quoted in a report by W. J. Dakin based on statements made by a U.S. colonel.

ment. During a raid on Darwin in July 1943 a formation of nine low-flying Japanese aircraft strafed every type of installation in the neighbourhood except the radar station, which was so cleverly concealed that it was invisible from the air. But it was not always practicable to conceal radar stations since the requirements for their operation sometimes conflicted directly with those for camouflage.

Ships observed from ships are often silhouetted against the sky, and under these circumstances camouflage is almost impossible; but ships seen from an aircraft against the background of the ocean may gain some advantage from appropriate colours. It was found that the most concealing colours in the dull misty weather of the Atlantic were, surprisingly enough, very light colours; but in the brilliant sunlight of the tropical waters of the Pacific, dull, dark grey blues offered better concealment. No colour or patterning was suitable for all conditions.

On behalf of the Research and Experimental Section of the British Admiralty the Camouflage Committee arranged for observations to be made at different latitudes of the relation between the intensity of light reflected from the sides of ships in sun and in shade and from the surface of the sea. With the help of a telephotometer devised by the National Standards Laboratory, Sydney, a thorough study of these factors was made in conditions of bright sun and of haze, and at dusk and dawn, and the results communicated to the Admiralty. However, as more and more ships and aircraft were equipped with radar, the value of such findings was greatly reduced.

R.A.A.F. pilots returning from England drew Dakin's attention to the fact that in the Mediterranean in calm weather the passage of a ship could be recognised when the ship was out of sight and over 50 miles away. It was due to some curious effect left on the surface of the sea in the ship's wake. Professor Earl made experiments with cheap solutions which by their action on the surface tension of the water markedly reduced this wake effect, but the results were considered to have no practical value at the time and the investigation was discontinued.

It would be a mistake to regard the energy and material expended on camouflage for civil defence and for the R.A.A.F. on the Australian mainland as misguided effort. Like many another precautionary measure it seemed essential at the time. If the Allies had not quickly gained aerial ascendancy in the South-West Pacific Area camouflage would undoubtedly have been of much greater importance than it was. If one factor emerged more clearly than any other from the experience with camouflage, it was the difficulty of coordinating scientific effort and defining limits of authority in a sphere of activity of interest alike to the armed services and civil defence.

MAPPING AND CHARTING THE CONTINENT

In Australia, in peace and war, the navy charted the seas round the continent and the army produced detailed contour maps: two scientific

tasks of great importance. The production of one-inch-to-the-mile contour maps was a task of the Army Survey Corps, established in 1909 when six experienced men were brought from England to form a nucleus. By 1939 the corps, recently expanded until it was about 100 strong, had produced 77 standard sheets (each, as a rule, 29 miles by 17½). These mainly covered relatively small areas round five capital cities and along the adjacent coasts.

In 1940 the mapping program was vastly accelerated. It was decided to produce, from data available in State Lands Departments and the Department of the Interior, a series of 4-inches-to-the-mile maps covering the coastal strip from Townsville to Port Augusta to 200 miles inland, the strip from Albany to Geraldton to 100 miles inland, and areas in Tasmania and the Northern Territory; and, with the help of civilian draftsmen in the Lands Departments to produce one mile and four miles to one-inch "emergency" maps of vital military areas while field survey units were being trained to produce standard one-inch maps. The program was steadily expanded, the quality improved, and the rate of output increased until, by the end of the war, the Survey Corps, then with a staff of about 1,800, had published 219 sheets on scales of 1:20,000 or 1:25,000, 645 sheets on a scale of one-inch to a mile (1:63,360) and 355 on larger scales. The one-inch sheets and those on smaller scales were distributed between the mainland and "the islands" thus:

	1 mile to an inch	1:25,000 and 1:20,000
Mainland	399	25
New Guinea mainland	118	93
Dutch New Guinea	6	8
New Britain	17	12
Bougainville	24	42
Borneo	83 (1:50,000)	39
Totals	647	219

Much of the mapping of the areas outside Australia had to be swiftly done and was based on inadequate data, as the troops painfully discovered, but the over-all achievement was immense. On the mainland the area covered by first-rate one-inch maps included, at the end of the war, still only a fringe round the eastern and south-eastern coasts and relatively small sections round Hobart, Adelaide, Perth, Wyndham and Darwin, but at the pre-war rate so much mapping would have taken more than 100 years. For Western Australia, for example, where there were only five sheets at the end of 1939, there were 75 in 1945. In the same period the number of Queensland sheets was increased from 12 to 130. Until 1940 sheets had been produced by the small Survey Corps at an average rate of fewer than three a year. In the six years from 1940 to 1945 sheets covering areas of the Australian continent, apart from those covering adjacent oversea territories, were produced at a rate of more than 50 a year.

The air force played a large part in these mapping achievements. The practice of using aircraft as an aid to mapping, which began during the 1914-18 war, was adopted in Australia about 1927. The first standard topographical map based partly on aerial photography was compiled by the Australian Survey Corps in 1936. In the war, as a result of their collaboration with specialist members of the American Armed Services, Australian cartographers were able to introduce new photogrammetric techniques and instruments and perfect them for Australian conditions. This work was greatly helped by Adastra Airways Pty Ltd. Towards the end of the war the government, aware of the importance of adequate mapping in the development of the Commonwealth's natural resources, set up an Aerial Survey Branch within the R.A.A.F.

The needs of the fighting Services also led to the production of a series of comprehensive geographical handbooks concerning the areas to the north of the continent, and to the compilation of much geographical information about Australia itself. Before the Pacific war began small teams in Australian Army Intelligence had been busy compiling the kind of geographical information that would be needed if military operations were undertaken in Australia. For example, in Eastern Command, from August 1940 onwards two officers—a geographer and an agricultural scientist—were employed collating topographical and military-economic information. They made military reconnaissances over as wide an area as they could in the time, and elsewhere collated information from Department of Main Roads, Shire Councils, the National Roads and Motorists' Association, the Lands Department, the Forestry Department, the University of Sydney and other sources. At its peak the staff employed on this work in Eastern Command up to 1942 totalled eight.

Early in 1942 an urgent need arose for geographical information about New Guinea and the Solomons. At this stage

> the framework for all topographical reports consisted of a series of rather indifferent maps compiled from government surveys and traverses by patrolling officers of the Civil Administrations, exploratory surveys by oil search companies, and sketches by missionaries. Hydrographic charts were also used but were in general quite faulty both as to depiction of land masses and offshore information. In addition there were available many useful reports of a geological and anthropological nature. No attempt had been made by military intelligence to collect this information, which was widely scattered throughout Australia in repositories of every conceivable nature. It was evident that the hard pressed intelligence staff was not in a position personally to search for it.[8]

In March Lieutenant Williams,[9] Government Anthropologist of Papua, was appointed by the Director of Military Intelligence to collect information about New Guinea and Timor. The staff of this section included only three officers when on 17th June General MacArthur's headquarters directed the establishment of a Combined Geographical Intelligence Section

[8] Operations of the Allied Geographical Section, GHQ, SWPA.

[9] Capt F. E. Williams, MA, BSc. (Served 1st AIF and in Dunsterforce.) Intell Corps, Angau. Govt Anthropologist, Papua, 1927-43. B. Malvern, SA, 9 Feb 1893. Killed in aircraft accident, 12 May 1943.

under an officer nominated by General Blamey, and including representatives of naval and air Intelligence and the Netherlands Indies forces. On 19th July G.H.Q. issued a second and more comprehensive directive establishing the Allied Geographical Section. This was at first commanded by Lieut-Colonel Mander-Jones,[1] an expert Intelligence officer until recently serving with the A.I.F. in the Middle East; on 1st August Major Blake[2] took over.

The section gradually developed into a fairly large organisation including many people with high qualifications not only in geography but also in various other studies, for example, geology, meteorology, navigation services, airfield construction, anthropology, engineering, and—of crucial importance—military Intelligence. By July 1943 it included 36 Australians and 3 Americans; by July 1944 84 Australians and 15 Americans; by July 1945 117 Australians and 77 Americans. The section published 110 terrain studies, 62 terrain handbooks, 101 "special reports", and other works. The terrain studies were comprehensive geographies, some of them covering more than 150 pages of text and including 30 or more maps. The handbooks, of which a total of 114,000 copies were distributed, were briefer but more up-to-date. The studies covered virtually the whole of the South-West Pacific Area and, eventually, much of Japan. One of the section's main achievements was the production with the cooperation of 76 Australian libraries of a four-volume work, *An Annotated Bibliography of the South-West Pacific and Adjacent Areas.*

The charting of Australian waters, which began with the Dutch and English navigators, became an organised service in 1860 when an agreement was made between the Admiralty and the Australian colonies for a series of surveys, the costs of which were to be shared. About 1890 the Admiralty began to employ surveying ships to chart the more isolated areas not covered by the earlier agreements. In 1922 H.M.A.S. *Geranium* was commissioned by the Australian Navy as a surveying ship, and in 1925 Captain Edgell[3] came to Australia to command H.M.A.S. *Moresby,* which worked in collaboration with the *Geranium.* From Captain Edgell the Australian navy surveyors learned the science of hydrographic surveying. The service was disbanded in 1929 until 1933, and then again on the outbreak of war. The demands of the Allied navies led to its being resumed and greatly increased until it consisted of two sloops (the *Warrego* and the *Moresby*), one frigate (the *Lachlan*), five corvettes, three tenders, two lighthouse tenders, and three harbour defence motor launches. Other vessels were attached to the service from time to time.

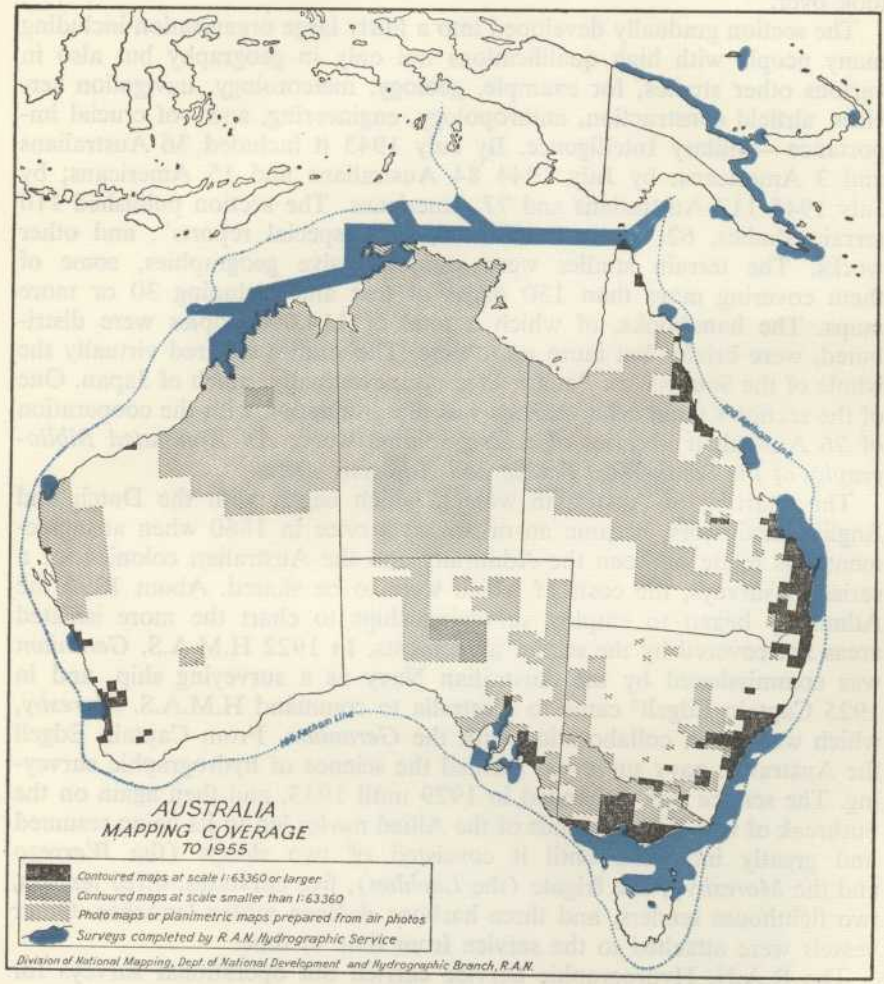
The R.A.N. Hydrographic Service carried out operational surveys for the Commander-in-Chief, South-West Pacific Area, and made extensive and complex surveys of the difficult waters of the Torres Strait and of

[1] Col E. Mander-Jones, OBE, ED; MA. Ch Instr, Sch of Mil Intell, 1944-45; Dep Dir of Mil Intell, Adv LHQ, 1945. Dir of Educ, SA, since 1946. B. Homebush. NSW, 6 Jul 1902.

[2] Col W. V. J. Blake, ED. (Served 1st AIF.) OC Army Section, Allied Geographical Section LHQ, 1942-46. Officer in British Colonial Service; of Kalorama, Vic; b. Sydney, 1 Feb 1894.

[3] Vice-Adm Sir John Edgell, KBE, CB, FRS; RN. (Served North Sea and Dardanelles in first world war.) Hydrographer of the Navy 1932-45. B. 20 Dec 1880.

northern Australia, along the northern coast of Arnhem Land and round to Yampi Sound. It also undertook the reproduction and printing of the charts for these areas and their distribution to the Allied services, and the reproduction of all Admiralty charts of the Pacific and Indian Oceans, and of Netherlands charts of the Dutch East Indies. During the war nearly 1,500,000 charts were printed in Sydney.



In 1946 an agreement was signed between the British Admiralty and the Australian Naval Board making the Hydrographic Office the charting authority for Australian waters and certain neighbouring islands. The work was carried on actively, and by 1955 the areas shown in the accompanying map had been surveyed.[4] As can be seen, much has yet to be done.

[4] The map and the material for this section are taken from "Contemporary Cartography. Hydrographic Service—Royal Australian Navy", *Cartography*, Vol. 1 (1955), p. 67.

The impetus given to mapping by the Services carried through after the war: the Government took the opportunity provided by the wartime advances to set up the National Mapping Office within the Department of the Interior, to arrange geodetic and topographical surveys and mapping for Commonwealth purposes and to coordinate them with similar activities of the States. Several years later the Department of National Development published the first numbers of the *Atlas of Australian Resources*,[5] an ambitious map-making project planned to cover in a series of approximately 50 maps almost every natural characteristic likely to affect the country's development.

[5] Edited by Dr Konrad Frenzel and published by Angus and Robertson Ltd.

CHAPTER 24

TROPIC PROOFING: THE BATTLE AGAINST MOISTURE AND MOULDS

ALTHOUGH military forces of different nations[1] had been maintained under tropical conditions for many years and must therefore have suffered the disabilities attendant on such climates, up to the second world war little or nothing had been done in a systematic and scientific manner to mitigate the often disastrous effects of tropical climates on military equipment. Scientists working in the tropics had encountered similar difficulties in relation to their experimental equipment and had to some extent been successful in solving their problems, but their results did not appear to have been widely known.[2] In pre-war days reliance seems to have been placed chiefly on spit and polish and oil of cloves.[3] Army equipment then was not as complex and vulnerable to hot humid climates as it became in later years. Whatever the explanation of the neglect, there can be no doubt that in the second world war tropical conditions were so extreme in some parts of the Pacific areas and Burma that it was found imperative to have the problem of maintaining equipment in these areas thoroughly investigated.

In New Guinea the deterioration of stores, noted first in the Port Moresby area where the climate was relatively dry, did not seem very important, but during the operations in the wet Milne Bay area the position became really serious. Radio sets, for example, failed completely and in the confusion of the resulting breakdown of communications advanced parties became lost.[4] On another occasion our troops went in to attack the Japanese with hand grenades, only to find the grenades fail completely. The actual cause of the failure of those particular grenades will never be known, but in the light of scientific knowledge it appears highly probable that it was due to a breakdown of the safety fuse in the ignition system. Potassium nitrate in the gunpowder of the safety fuse would, under conditions of high relative humidity (greater than 94 per cent) become damp and pass into solution, thus preventing its being fired.[5] An equally disastrous experience occurred with mine detectors. There were no means for checking the detectors just before going into action, and a number of areas in the Milne Bay region were examined

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[1] The British in India and Malaya; Dutch in Indonesia; and Americans in Panama.

[2] H. A. Dade, "A Biologist in the Tropics". *The Scientific Journal, Royal College of Science,* Vol. 10 (1940), p. 67.

[3] W. D. Chapman, "Prevention of Deterioration of Stores and Equipment in Tropical Areas", *Journal of the Institution of Engineers of Aust,* Vol. 22 (1950), p. 269. Dr Chapman states that ½ pint per man per annum of oil of cloves was included in the British tropical scale of medical stores. As the only use that could be imagined for this store was in the treatment of dental decay it was deleted from the Australian scale!

[4] There were probably other reasons for the breakdown. Many sets had already been in use in the Middle East for a year or two, and were not in good condition when they arrived in New Guinea.

[5] R. Burns, *Proceedings of the American Society of Testing Materials,* Vol. 36 (1936), p. 600.

by detectors and declared free from land mines. Tanks moving into these areas were met with exploding mines. Here again the cause of failure of the detectors used was never determined, but from later investigations there was little doubt that it was due to a breakdown of the dry batteries of the detectors. Dry batteries were a constant source of trouble in the tropics until proper care was taken in packing and storing them.

Port Moresby enjoyed a dry climate for some months of the year, but at Milne Bay, for example, high relative humidities prevailed throughout the year. The accompanying table shows the average relative humidities for the months of April and May 1943 at Milne Bay, at various times of the day. These high humidities at mean temperatures of about 75 to 77 degrees combined to make a climate as uncomfortable and extreme as almost anywhere in the world.[6]

Time	0300	0600	0900	1200	1500	1800	2100
April	94	95	88	85	81	84	94
May	95	96	89	86	83	87	93

Reports filtering back from the fighting areas made it clear that great trouble was being experienced with the deterioration of all kinds of equipment. There was nothing in the reports to suggest a basis for a planned attack on the problem. In the absence of any information from overseas Australia was thrown on her own scientific resources during the critical months of the campaigns in New Guinea. Although whatever action could be taken immediately was taken by the Branch of the Master-General of the Ordnance, which was fully aware of the many difficulties being met, it was clear that the problems of rendering the many hundreds of different kinds of equipment proof against the ravages of tropical climates could not be completely solved in a week, or even in months.[7] The Commander-in-Chief of the Australian Military Forces, Sir Thomas Blamey, perturbed by the incidents related earlier and the reports of his Equipment Directors, was emphatic on his return from a period in New Guinea late in 1942 that something must be done—and in a hurry—to prevent the deterioration of war materials.

Here, plainly, was a scientific problem of the first order of magnitude, for the solution of which no systematic preparations had been made. Though the factors mainly responsible for deterioration of materials in the tropics were few in number, the great variety of materials affected by them made it necessary to deploy a correspondingly wide range of scientific knowledge and skills. It was also evident that any attack on the problem of preventing deterioration of materials would necessitate coordination of scientific resources to the widest extent possible.

On 14th May 1943 Ashby called a conference of representatives of the various Services of the Australian and United States Forces, the

[6] More extreme conditions occur in parts of the Amazon Valley and in the worst regions in Africa, but conditions in some parts of New Guinea were appalling and comparable with these.

[7] Before May 1943 a whole range of items had received some attention from the MGO including the protection of ferrous and non-ferrous metals, packaging, electrical and optical equipment, timber, leather, boots and fabrics.

Department of Munitions and other government departments,[8] to discuss the problem of preventing the deterioration of supplies and equipment under tropical conditions. The conference decided that the first thing to do was to collect accurate information, and recommended that a mission be sent immediately to operational areas for this purpose.[9] General Blamey gave his approval to these proposals. The terms of reference of the mission were:

1. To collect information on the problem of resistance and/or deterioration of stores and equipment under tropical conditions.
2. To obtain and bring back, or send forward, representative samples of deteriorated stores or equipment.
3. To submit a report setting out the problems as seen and wherever possible to make recommendations as to priority or urgency of the matters covered.

Before going north to the operational areas the members of the mission discussed different aspects of the problem with organisations likely to be concerned;[1] in this way they prepared themselves to make recommendations on the spot where the remedies could be carried out immediately. Anticipating that much of the scientific work likely to be involved in devising remedies would for some time to come centre on the study of moulds and fungi, the Scientific Liaison Bureau formed a Mycological Panel in May 1943.

In New Guinea, especially in the Milne Bay area where at the time of their visit conditions were ideal for such studies, the mission made a thorough investigation of the problem of deterioration. Its report contained numerous striking photographs showing the astonishingly destructive action of tropical climates on all kinds of stores and equipment.[2] Owing to the continuously high relative humidity and fairly high temperatures, all the processes of deterioration active in temperate climates are greatly accelerated in the tropics. Of the two factors, relative humidity is the more important.[3] Much of the deterioration arose from the attacks of fungi,[4] whose growth is specially favoured by tropical conditions. Metallic corrosion was also greatly speeded up.

In spite of the early efforts of the army's Equipment Directors the economic losses in New Guinea were clearly enormous: up to the time of the mission's visit they were estimated to be in the neighbourhood of several million pounds. The monetary loss was of minor importance compared with the loss of operational efficiency caused by the drain on man-

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[8] Dept of Supply; P.M.G's Dept; Dept of Home Security; C.S.I.R.; and Chemical Defence Board.

[9] The mission consisted of: Col W. D. Chapman (Chief Superintendent of Design, MGO Branch), Leader; Dr C. J. P. Magee, mycologist and senior scientific member; C. T. Hansen, chemist; C. Kerr Grant, physicist; Maj W. K. Marshall, Branch of the QMG; Maj S. L. Leach, Branch of Chief of the General Staff; F-O G. H. Payne, Directorate of Technical Services, RAAF.

[1] Depts of the Army and Air; C.S.I.R.; Ordnance Prodn Dir; Munitions Supply Labs; Dept of Commerce; A.W.A.; S.T.C.; and J. W. Handley Pty Ltd.

[2] C. J. Magee, C. T. Hansen, C. Kerr Grant, *Report on the Condition of Service Matériel under Tropical Conditions in New Guinea.*

[3] An interesting illustration of this fact is to be found in the opposite effect of extremely hot dry conditions such as obtain in the Valley of the Tombs in Egypt. When King Tutankhamen's tomb was opened in 1922 for the first time in 4,000 years, linen shawls which had been cast over gold and silver treasures were still recognisable.

[4] Fungi include organisms known as moulds and mildews.

power needed for reconditioning unserviceable or unreliable equipment. Not only was efficiency reduced, but troops ran greatly increased risks to their lives through failure of equipment at critical moments.

The mission made a detailed examination of the nature of the deterioration of hundreds of items, including vehicles and vehicle spares; airframes, aircraft engines and instruments; armament, ammunition; radio and other electrical equipment; optical instruments; tents, parachutes, clothing, boots, timber and food. It noted the extent of the deterioration of materials up to the time of their arrival in New Guinea, during storage and during their subsequent use in the field. Mindful of the need for prompt action, it made recommendations in the light of the scientific and technical knowledge then available to it, of the best methods of dealing with the different problems presented. At the same time it was well aware that many of the suggestions made were tentative only and that more experimental work was required, not only in the laboratory but in the field of military operations. The mission described the facts as it found them without any sense of criticism and without attempting to be wise after the event. Many improvements had in fact already been suggested by the technical branches of the army, and only the inevitable time lag in giving effect to them in the mass production of equipment had prevented their being carried out by the time of the mission's visit. Nevertheless a great amount of work remained to be done. The mission's report was promptly published and widely circulated. Its greatest usefulness lay in the extent to which it made manufacturers and scientists aware of the problems being faced by the army in the tropics. The influence of the report was not confined to Australia; it received favourable notice from military authorities in Britain and in the United States.

On 30th November 1943 another general conference, attended by fifty-four representatives of the Australian and American Services and of Commonwealth departments, was called to consider what action should be taken on the report of the Scientific Mission. At the May conference little consideration had been given to coordinating the different lines of attack on the problems of tropic proofing,[5] and it was left to the various laboratories to do this for themselves. The army now felt that something more definite was required. In the course of its deliberations the conference drew up a general plan of campaign. In order to avoid duplicating work for the different Services, it appointed Inter-Service Committees to deal with those phases of the problem of tropic proofing then considered most pressing: 1. Packaging, 2. Corrosion Preventives, 3. Electrical Equipment, 4. Organic Materials, 5. Optical Instruments.[6] Coordinating the work of these committees was the function of the Scientific Liaison Bureau.

The spearhead of the attack on problems of tropic proofing was made in the laboratory. Here, for example, methods were worked out for treating materials, such as canvas and leather, to render them immune to the

[5] The alternative term tropicalisation was used mainly in Britain.

[6] A sixth committee, for the underwater protection of ships and small craft, was added in Feb 1944.

attack of moulds and mildews. Once this had been achieved it was the function of the relevant committee (in this instance No. 4), with the help of organisations such as the Munitions Supply Laboratories, the Departments of Agriculture of New South Wales and of Victoria, and of the Mycological Panel to formulate codes of recommended practice; specifications were then published by the Standards Association of Australia. The Scientific Liaison Bureau coordinated all these activities, acting as a clearing house for information on tropic proofing, whether from Australian or oversea laboratories and committees.

It is perhaps not surprising that in the next few months it was found necessary to make some changes in this pattern of activities. Responsibility for the coordination of work on electrical equipment was transferred to Committee L of the Services, laboratory work to the C.S.I.R. Section of Electrotechnology, and that on optical instruments to the Optical Munitions Panel.

The bureau gave valuable help to manufacturers by making a survey of scientific laboratories to which they (the manufacturers) could apply for help in solving the different types of problem met in tropic proofing. This list of laboratories and a brief sketch of the kind of work that was being done in each, was published in one of the series of technical supplements (No. 7) to the bureau's publication *Science on Service*.

The problem of conserving material in the tropics resolved itself into two main parts:

(*a*) that of determining suitable procedures for packing, handling and storing materials. It was estimated that about 75 per cent of the deterioration noted arose from defects in these operations.

(*b*) the devising of methods of treating equipment and stores—"tropic proofing" them—to resist the action of excessive humidity and its secondary effects. These would include methods for the prevention or delaying of the corrosion of metals, for the prevention of the rotting and decay of organic materials brought about by fungi, and the breakdown of the insulation of dielectric materials.

A few of the broader aspects of the problem will be considered.

The pre-war techniques of packaging goods in Australia lagged behind those of other countries such as the United States. Nowhere were these deficiencies more strikingly brought to light than in New Guinea. Australian packing cases were frequently unsuitable in design and so weak in construction that they were easily smashed by pilferers or by careless handling. Waterproof linings were not generally used, and when they were the goods were sometimes packed in such a way—with insufficient cushioning to hold them in place—that the linings were broken. Extensive corrosion of metal parts was caused by packing with inadequately dried cushioning and internal wood furniture, and also by a failure to use properly compounded rust-preventive coatings. That Australian methods of handling stores were not up to standard is clear from the mission's report:

United States Forces' equipment arrives at forward depots in a far better condition than Australian Forces' equipment. This is attributable not only to the fact

that their packages are more resistant to rough handling, but also to faster unloading and transfer rendered possible by superior equipment and the more efficient system of handling and tallying.[7]

As a means of remedying this situation courses of instruction on packaging and preservation were instituted by the Master-General of the Ordnance Branch and given in all States to Ordnance, Royal Australian Engineer and Army Inspection personnel, to the Departments of Munitions and Supply, and to contractors. The first of these was given on 27th September 1943 in Melbourne. Exhibitions were arranged of packaging and demonstrations of tropic treatments as used in ordnance depots were given.

Serious defects were also found in conditions of storage. Many prefabricated huts of a design which had proved satisfactory in the arid conditions of the Middle East were found to be quite useless in New Guinea, mainly because of insufficient allowance for circulation of air. The most important requirement of a hut for storage in the tropics is openness of construction. The natives had achieved this with their thatched huts, and it was by adapting native structures that the problem of housing stores in New Guinea was largely solved. Tarpaulins which had been found quite satisfactory in excluding dust in the Middle East were worse than useless in New Guinea when used as temporary covers to drape stacks completely and to overlap the ground, because they caused considerable losses from corrosion and moisture absorption by creating underneath them a tropical atmosphere of the worst kind.

For storing special equipment such as bombsights and reconditioned spark plugs, "hot boxes", depending for their effect on the reduction in relative humidity brought about by heating air, were found so effective that the Scientific Mission recommended that they be supplied to all workshops, field parks and signal units. Air conditioning, considered highly desirable but impracticable in operational areas, was held to be justified at bases where large quantities of optical and electrical equipment might be stored. As far as the mission could discover, air conditioning was not tried out in New Guinea, but an attempt was made to air-condition a workshop used for the repair of optical instruments.

Where exposure of materials in humid conditions was unavoidable, as it often was, one of the most effective methods for preventing the decay caused by fungi was to apply chemicals inimical to their growth—fungicides or fungistatics.[8] Many substances were known to have this property but at that time the effectiveness of only a few had been at all thoroughly investigated in the laboratory. Dr Jensen,[9] a member of the Mycological Panel, working in the Department of Bacteriology in the University of Sydney, began a systematic examination of the toxicity of mould proofing or fungicidal chemicals against fungi typical of the microflora found on

[7] Even so one American authority estimates that less than 50 per cent of the American matériel sent to the tropics reached its destination in a satisfactory condition.

[8] Fungicides killed the growth, fungistatics prevented the growth from developing and reproducing.

[9] H. L. Jensen, DScAgr. Bacteriologist to Linnean Society 1927-47; Director of Plant Culture, Dept of Bacteriology, Lyngby, Denmark, since 1948. Of Denmark; b. Denmark, 27 Jun 1898. While in Australia Jensen did most valuable work on plants and soils, particularly for N.S.W.

materials that had undergone deterioration under conditions of tropical warfare.[1]

At the outset Jensen hardly hoped to find an ideal fungicide suitable for universal use, since the materials to be treated varied widely and the organisms against which protection was sought were almost equally varied. He paid particular attention to the conditions under which the substances tested were likely to be most active. A useful fungicide must conform to other requirements than toxicity against a wide variety of fungi.[2] It should not be poisonous to human beings or irritating to the skin; it should be stable and resistant to leaching, and odourless or at least pleasantly odoured; non-corrosive to metals and not harmful to other materials on which it might be applied. These requirements considerably reduced the number of chemicals likely to be suitable as fungicides.

Failure due to tropical conditions was found to be more troublesome with electrical and radio equipment than with almost any other; the difficulties were probably greater because this was equipment with which the Services had had little or no previous experience in the tropics. It was soon evident that one of the main causes of deterioration of radio and other electrical equipment in the tropics was the effect of moisture on electrical insulation, the effect of relatively high temperatures alone being negligible. In some materials, such as glass, ceramics and mica, breakdown of insulation was due to adsorption of moisture on the surfaces; in others, such as wood flour-filled phenolic moulded resins, it was due to penetration of moisture deep into the body of the material. Surface electrical leakage, caused by gross condensation of moisture, was often accentuated by mould growth. Moulds, among the most ubiquitous of living organisms, grow especially well in tropical climates because of conditions of high relative humidity. To inhibit their growth it is only necessary to keep the relative humidity below about 70 per cent.[3] A mould needs food for sustenance, which it finds in the form of organic materials such as cellulose fibres (cotton fabrics, paper, and wood), waxes, leather and oils (except those of mineral origin), together with some mineral salts. Moulds were not in themselves the main cause of damage to electrical equipment. As a rule electrical equipment broke down through moisture absorption before moulds had time to grow. Their subsequent appearance was a confirmatory symptom of moisture absorption, and the longer they were allowed to grow the more difficult it became to reclaim the damaged equipment. Prevention of mould growth alone by treatment with anti-mould chemicals did not provide a remedy for breakdown of electrical equipment. The trouble was usually more deep-seated.

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[1] H. L. Jensen, "Observations on Properties of Certain Fungicidal Compounds", *Proc of the Linnean Society of NSW*, Vol. 71 (1946), p. 119.

[2] Many of the fungi used by Jensen were identified by Dr Lilian Fraser and Mr G. C. Wade. On the physico-chemical side of his work he was helped by Mr R. J. Goldacre, Wellcome Research Fellow in the Dept of Organic Chemistry, Univ of Sydney.

[3] Temperature also has an important influence on the growth of moulds: below 68 degrees fahrenheit growth is very slow; few can survive temperatures above 113 degrees; they do best in the range 77-104 degrees.

After the failure of the radio equipment at Milne Bay, manufacturers began empirical tests to find remedies, since something had to be done with all possible speed. On the commercial side the Materials Testing Laboratory of Amalgamated Wireless (Australasia) Ltd, under the direction of Mr Healy,[4] was easily the most active organisation.[5] As a result of experience with its own equipment, which was among the first to be sent to New Guinea, work was begun in the A.W.A. laboratory well before the official inquiry by the Scientific Mission. The company had been shipping to New Guinea radio equipment that had been carefully packed in wood wool, a ready absorber of moisture and consequently a supporter of mould growth. Much serious deterioration of equipment was traced back to this cause. Furthermore, owing to the fact that soft woods were not available, unseasoned hardwood had been used as furniture in packing. A great deal of corrosion arising from the escape of acetic acid and other vapours from the unseasoned timber occurred as a result of this procedure. Remedies of different degrees of efficacy were soon worked out. Although much more detailed and extensive investigations were later carried out by other organisations, special credit is due to A.W.A., whose efforts at a critical time did much to stem, temporarily at least, the disastrous effects of tropical conditions on telecommunication equipment.

In the government institutions responsibility for laboratory studies of the deterioration and preservation of telecommunication equipment intended for use under service conditions was accepted by the Council for Scientific and Industrial Research. Investigations were undertaken by the Electrotechnology Section, which coordinated the work of other collaborating bodies.[6]

The immediate objective of the early investigations was to find some means of extending the life of existing equipment, particularly field signals equipment already in service. The best remedial treatment found was to dry the equipment in an oven and then to coat the appropriate surfaces with varnishes or other materials, finally baking the set once more at about 160 degrees Fahrenheit. This was the procedure, based on the work of A.W.A., recommended by the Scientific Mission and put into effect during its visit to New Guinea.[7] Back in the laboratories, tests were made to measure the efficacy of films of different coating materials. The work was undertaken first by A.W.A., later by the C.S.I.R., and finally, on a large scale, by the Munitions Supply Laboratories. Since films were applied solely for the purpose of excluding moisture it was imperative that some means should be devised for appraising their efficacy. By means of well-established scientific procedures the Australian laboratories were able to

[4] C. P. Healy, BE. Electrical engineer and research officer, Amalgamated Wireless, since 1933. B. Melbourne, 7 Oct 1898.

[5] C. P. Healy, "Deterioration of Radio Equipment in Damp Tropical Climates and Some Measures of Prevention". *A.W.A. Technical Review*, Vol. 7 (1946), p. 103.

[6] Munitions Supply Labs, P.M.G. Labs, Design and Inspection Branches of the Services, laboratories in industry such as those at A.W.A. and S.T.C.

[7] This method of tropic proofing was later used by the manufacturers. It was found to be more effective when done by the manufacturer than in the field, as better control of conditions could be maintained in the factory and components could be treated more effectively before assembly than after.

discard all but two of the commercially available coating materials, namely phenolic and glyptal resins.

After the Munitions Supply Laboratories had completed its extensive investigations, the Standards Association of Australia prepared specifications outlining the performance to be expected from suitable coating materials. In the United States fungicides such as salicylanilide and pentachlorophenol were added to varnishes, in amounts of up to 15 per cent, but unfortunately these agents considerably reduced the moisture-resistance of the coatings. Australian practice and experience showed that the addition of a fungicide was unnecessary if good-quality varnishes were available and were properly applied.

The application of moisture-resistant finishes such as varnishes and waxes delayed, but could not prevent, progressive deterioration. Nevertheless treatment of this kind was undoubtedly worth while since it ensured the satisfactory performance of equipment for several weeks at least under extreme conditions. Repetition of the treatment in the field was found less effective than the first one. Easily the most important factor of all in helping to prolong the useful life of electrical equipment was its regular use and intelligent maintenance. Obvious as this precept may appear, it was by no means universally recognised and practised.

The problems arising out of experience in the tropics were new to the great majority of radio manufacturers in all parts of the world,[8] and it was clear that they would yield only to a planned and systematic attack leading to complete redesign of equipment. One of the first steps was to simulate in the laboratory the atmospheric conditions to which equipment was exposed in the field so that it could be tested without the delay of sending it to damp tropical areas.

To shorten the duration of the tests, so that an indication could be obtained in a few days of the probable condition of equipment after some months in the field, accelerated deterioration was produced by exposure at temperatures and relative humidities much higher than those likely to be experienced in the tropics. It was one thing to produce relative humidities of between 90 and 100 per cent at temperatures ranging from 75 to 100 degrees Fahrenheit, but quite another to measure the relative humidities accurately, hold them constant, and reproduce them throughout a moderately large volume of space. A considerable amount of investigation had to be undertaken and special instruments—such as electric psychrometers—were devised for measuring and controlling humidities. Controlled humidity chambers were developed by the National Standards Laboratory and Amalgamated Wireless (Australasia) Ltd, capable of maintaining a high humidity, say 96 per cent, to within two per cent for temperatures ranging from 86 to 149 degrees Fahrenheit.[9] With the

[8] Notable exceptions were the firms of Philips (Holland), which had for some years been supplying the Dutch East Indies with equipment, some at least of whose component parts had been tropic proofed; and the Humble Oil Co, of America, which had applied sound methods of design and protection of electronic instruments for oil prospecting in New Guinea before 1939.

[9] L. G. Dobbie, "Investigation into Tropic Proofing of Electrical Materials, 1943-46. I. The Protection of Electronic Equipment for use under Humid Tropical Conditions". *Aust Journal of Applied Science*, Vol. 1 (1950), p. 80. Also "The Protection of Telecommunication Equipment Exposed to Humid Tropical Conditions: Investigations in Australia". (Unpublished.)

experience that had been gained in the construction of these chambers the Munitions Supply Laboratories were able to build even better ones.

As more efficient techniques for testing damp, tropical conditions were developed, detailed investigations were undertaken (*a*) to find out what materials were unsuitable for damp tropical use and to eliminate them from electrical equipment, and (*b*) to find out what materials were immune to tropical influences and to employ them if possible. If the use of materials with undesirable reactions to tropical influences was unavoidable, it would be necessary to find some way of improving their durability.

In their approach to tropic proofing and tropic design, all organisations at first kept the applied side of their work steadily in view and on the whole concentrated on *ad hoc* problems.[1] The C.S.I.R. later introduced into its program longer range and more fundamental investigations. For example, extensive and accurate studies were made of the influence of moisture on a wide variety of insulating materials.[2] It is not always easy to dissect out of published reports and papers the exact contributions of the main organisations concerned: Amalgamated Wireless (Australasia) Ltd, the C.S.I.R., the Scientific Mission in New Guinea, the Branch of the M.G.O., the Department of Munitions, the Standards Association of Australia and the Institution of Radio Engineers of Australia, all contributed their share.[3] Suffice it to say that tropic proofing called for extensive team work in many branches of science and each team did an excellent job. In general, success in meeting tropical conditions was achieved by proper choice of materials, and with telecommunication equipment the use of appropriate mechanical and electrical designs.

Some materials, such as polystyrene, polyethylene and polyvinyl chloride, were found to be very resistant to water, absorbing none even on their surfaces. These materials maintained their electrical insulation under conditions of high humidity, but because of dimensional instability at high temperatures they found only a limited use. Glass and properly vitrified ceramics were perhaps the most stable of all insulating materials and were well suited to use in tropical conditions, except for two drawbacks: though water could not penetrate the bulk of these materials, in conditions of high relative humidity it was adsorbed on their surfaces and their electrical surface leakage might become serious; on account of their fragility they could be used profitably only at some points in radio equipment. They could replace, to a limited extent only, phenolic resins and other plastics which lent themselves much more readily to mass production. Experiments in the Electrotechnology Section during 1944 confirmed work done overseas,[4] showing that the resistance of these materials under damp conditions could be greatly improved by coating them with organosilicon

[1] C. P. Healy, *A.W.A. Technical Review*, Vol. 7 (1946), p. 103.

[2] J. S. Dryden and P. T. Wilson, *Aust Journal of Applied Science*, Vol. 1 (1950), p. 96.

[3] See also the Reports on the Deterioration of Telecommunication Equipment in Tropical Areas by Radio Mission of the Inst of Radio Engineers, Australia, by C. S. Gittoes, D. W. Rowed and R. J. Collins (Leader of the mission).

[4] F. J. Norton, *General Electric Review*, Vol. 47 (1944), p. 6.

compounds (methyl-chlorosilane and ethyl-chlorosilane) and also, though not quite so well, with certain quaternary ammonium compounds.[5]

Owing to the fact that this work was done so late, little application was found for it during the war. The kind of use made of it some time afterwards may best be illustrated by an example from the experience of the Crown Crystal Glass Company, which had the contract of supplying the P.M.G. Department with glass insulators. A batch of 750,000 line insulators failed to meet the rigid tests laid down in the specifications. After treatment with an organosilicon compound they were found to be quite satisfactory, and this large batch was saved. Organosilicon films did not, however, prevent condensation of moisture. Tests showed that under given conditions the amount of moisture that condensed on them was about the same as on untreated glass. In spite of this, however, high insulation of the treated surface was maintained. Presumably, on the treated surface the condensed moisture was in the form of isolated droplets with large intervening areas free from moisture. Good insulation was obtained only if the surfaces were kept free from dust. The astonishing thing was that glass surfaces treated with methyl-chlorosilane and ethyl-chlorosilane retained their insulation even when held in steam over boiling water. Results of the work on these coatings were of considerable value after the war in the manufacture of equipment for climates less exacting than those of the tropics. As already pointed out, the tropics merely accentuate and hasten processes normally operative in temperate climates.

Most of the insulating materials with physical properties that lent themselves to the mass production of radio parts proved to have only moderate moisture resistance. For example, laminated phenolic plastic materials upon the paper or fabric filler of which moulds grew with the greatest ease, were so suitable otherwise for radio equipment that there was a strong incentive to try to improve them. Experiments in the Electrotechnology Section showed that phenolic resins containing mineral fillers such as mica, slate flour or kaolin, were much more resistant to moisture, and therefore to moulds, than those containing paper and fabric fillers. Mica-filled phenolic resins performed well under conditions of high relative humidity and were used in the manufacture of valve bases, sockets, connectors and many other components.

Because of their permeability to moisture and their tendency to become brittle and crack, protective films of varnishes, waxes and bitumen had only moderate value as a means of protecting insulating materials. In general the more absorbent an insulating material is, the more it tends to swell as it absorbs moisture, and it will in time burst even the best protective coating film. The paper and fabric fillers in synthetic resin-bonded sheet were particularly unsatisfactory in this respect. An additional complication was that insulating materials which absorbed water often caused corrosion of metal electrodes in contact with them.

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[5] R. J. Meakins, *Australian Journal of Applied Science*, Vol. 1 (1950), p. 120.

It gradually became evident that there was no perfect system of preventing the deterioration of the electrical properties of insulators from heat, moisture, sunlight and dust by the use of coating materials alone. Any film of coating material through which air can penetrate is also permeable to water vapour, since molecules of water are roughly the same size as those of oxygen and nitrogen. In other words, to exclude water vapour completely it was necessary to erect a barrier that would also prevent the penetration of air. The only way of doing this was by hermetic sealing. This involved complete enclosure of the equipment in an envelope of impermeable materials, such as metals, glass or ceramics.[6] Manufacturers were thus placed in a dilemma: to introduce hermetic sealing would have involved changes in design which would seriously reduce an already slow rate of production; to do less was to accept the only temporarily successful "tropic proofing". As is usual in such circumstances, a compromise was achieved by the gradual introduction of new designs.

Strange as it may seem, hermetic sealing of single components proved more difficult in most cases than sealing complete equipment. Nevertheless sealing of components was successfully applied to paper dielectric capacitors, transformers, and inductors (used for audio and power frequency work), all of which had given considerable trouble in the tropics. Sealing of components provided an obvious application of surface treatment techniques, and experiments were made on the treatment of different types of glass-to-metal and ceramic-to-metal seals, particularly with organosilicon compounds.

The most effective protection of electrical equipment against moisture was attained by enclosing the whole equipment in a metal case using synthetic rubber gaskets and glands, which did not provide a truly hermetic seal but unlike glass and ceramic were not easily destroyed by rough handling. There were considerable practical difficulties in the way of a general application of hermetic sealing, such as the provision for the dissipation of heat generated during the operation of the equipment, the prevention of leaks through gaskets, glands for rotatable shafts, and passages created by mechanical damage or imperfect fits, but they were gradually overcome. It was customary to include within the sealed equipment a desiccant, usually silica gel. This was easily reactivated and would absorb water up to 40 per cent of its dry weight before allowing the relative humidity of the enclosed space to rise above 80 per cent. Even when sealed in this manner, equipment had to be opened up for inspection and maintenance, so that a judicious and thorough application of anti-corrosive and moisture-resistant finishes was still found necessary. Wireless Set No. 22 Australian, and Telephone Set "L" No. 2 Australian, hermetically sealed and treated in this manner, were highly commended by the army for their improved performance. Since portable army equipment was often subject to more severe conditions than any other—in amphibious

[6] S. A. Prentice, "Some Wartime Problems with Electrical Insulating Materials", *Journal of the Inst of Engineers*, Vol. 17 (1945), p. 197.

operations, foot-slogging jungle patrols and exposed observation posts—this was praise indeed.

Electric batteries, especially those made up of dry cells, underwent marked deterioration in the tropics, much of which was traced back to faulty packing. Dry cells had an unusually short shelf life in the tropics and in service failed most noticeably in wireless sets and mine detectors. To make matters worse, they had often passed their expiry date before being taken into service. High-tension dry batteries made with the customary untreated cardboard containers were quite useless in the tropics. A good deal of the deterioration in batteries was due to leakage between cells caused by sodden cardboard partitions. Impregnation of the cardboard with paraffin wax did not greatly improve matters, since the treatment was effective for a few weeks only. It required considerable effort to persuade battery-making firms to adopt the necessary tropic proofing precautions,[7] the most effective of which were more careful packaging in general, avoidance of cardboard in any form in the construction of the battery, sealing the cells in metal cases filled with plastic bitumen, and storing in refrigerated stores.

While durability of radio equipment in the tropics depended primarily upon the care taken in manufacture, it was still necessary to issue detailed instructions for its maintenance. Only by attention to both factors was it possible towards the latter part of the war to be sure of the reliable performance of radio equipment in the tropics.

The information gained as a result of these investigations proved of considerable assistance after the war in the design and production of equipment in other fields besides telecommunications, such as navigation and meteorology; it also helped to improve considerably the performance of domestic radio sets in the less severe but at times somewhat humid climates of northern and north-eastern Australia.

It probably came as something of a surprise that optical instruments of all kinds were so seriously affected by the tropics. Owing to the growth of moulds and fungi, often on organic debris on the lenses and prisms themselves, instruments became, temporarily at least, quite useless. In the early days of the campaign in New Guinea practically all instruments were affected, especially binoculars, the most generally used optical instruments.[8] The marked susceptibility of binoculars was attributed to their ineffectively sealed construction and the amount of air exchange between the instrument and surrounding air because of "breathing"[9] and the movement of the eyepieces during focusing. Even among fixed focus instruments where there was no movement of eyepieces, fungal infection of the

[7] Brig W. D. Chapman, personal communication.

[8] Lt-Col A. G. Wilson, touring as an observer in New Guinea at the end of 1943, records that the commander of one battalion had had three pairs of binoculars in twelve weeks.

[9] This refers to the exchange of air between the inside and outside of the instrument, caused by changes of temperature and pressure. If at night when air was drawn into an instrument by cooling, the temperature fell below the dew point, the moisture deposited was more or less trapped and would therefore accumulate.

interior of the instruments still occurred. At Milne Bay, instruments such as the No. 7B Mark 2A Director were found to be quite useless although they had not been out of the store.[1] American and Australian instruments alike were affected and mechanics at base workshops were unable to cope with the continual stream of instruments coming in for cleaning. In the process of cleaning, graticules were often accidentally rubbed off, thus putting the instruments out of commission for a much longer period until the graticule was replaced. In extreme cases the by-products of fungal growths caused permanent and irreparable damage to the lenses by etching the glass.[2]

Fungal growths often blocked vision altogether. The problem of tropic proofing optical instruments was therefore different from that met with in radio and electrical equipment where fungal growth was of secondary importance and generally symptomatic of earlier moisture absorption by insulating materials. With optical instruments, tropic proofing resolved itself into what was essentially an attack on the moulds themselves. Confronted with the problem in the field, the Scientific Mission did its best to discover remedies that might be applied immediately. In the treatment of binoculars it suggested sterilising the instrument by placing it in a cabinet filled with the vapour of methyl alcohol and then painting the inside surfaces with a solution of a fungicide salicylanilide in methylated spirits. It recommended that the large accumulation of mouldy instruments, too numerous to be dealt with by the workshops at Milne Bay and Port Moresby, should be sent back to Australia as soon as possible in order to avoid destruction of the optical surfaces. Once again the procedures recommended were only palliatives to be adopted pending a more thorough investigation of the problem.

Although the occurrence of fungal growths on optical instruments had been known for long enough, no systematic and scientific study had ever been made of the factors involved in their growth. While the mission was making its investigations in New Guinea, the Scientific Instrument and Optical Panel set up a Tropic Proofing Committee under the chairmanship of Professor Turner.[3]

Special committees were also appointed by Britain and the United States, and tropical stations to test the efficacy of methods of tropic proofing were set up at Lae (by Australia), at Ibadan in West Africa (by Britain), and in the Panama Canal Zone (by the United States).

The fungal growths found on and inside optical instruments were saprophytic moulds or mildews, which do not contain the pigment chloro-

[1] It would be equally true to say *because* they had not been out of the store. A great deal of deterioration took place in stores because of the conditions obtaining in them.

[2] This phenomenon had been noticed by Mr C. E. Lane-Poole in the course of a survey of Papuan and New Guinea Forests in 1923.

[3] Other members of the original committee were: J. W. Blamey, W. Caldwell and P. G. Law (Secretary), Physics Dept, Univ of Melbourne; Assoc Prof Ethel McLennan and E. Matthaei, Botany Dept, Univ of Melbourne; G. C. Wade, Vic Dept of Agriculture.

The committee acknowledged valuable help from: Dr J. S. Rogers (Secretary Optical Panel); Prof V. M. Trikojus (Medical School, Univ of Melb); G. M. Willis (Metallurgy School, Univ of Melb); C. T. Hansen, J. Rischbeith, A. G. Sussex and A. Temby (Munitions Supply Labs); E. R. Johnson and J. S. Dryden (Physics Dept, Univ of Melbourne); and M. M. Pack (B.A.L.M. Melbourne).

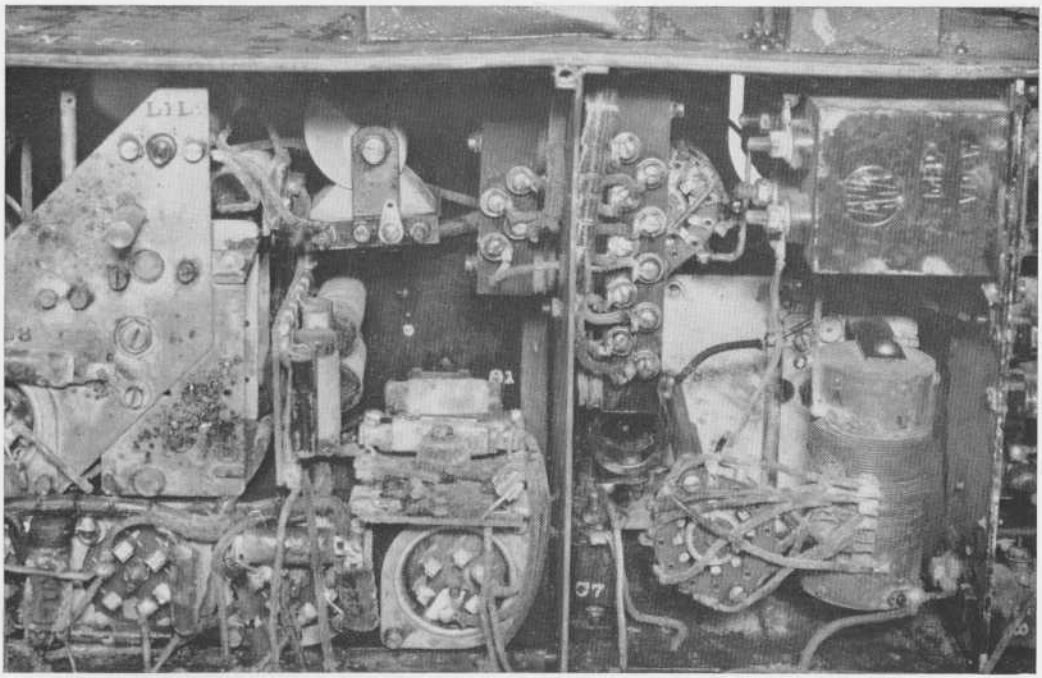
phyll and are therefore unable to manufacture, as do the higher plants, the starches and sugars they require. Unlike the higher plants, they are able to grow in the absence of light. Parasitic fungi depend for their organic nutrients—such as the sugars and starches—on living material; saprophytic fungi get their food from dead material of organic origin—leather, wood, paper, straw, cardboard, and the like. The moulds found in optical instruments, and indeed in all army equipment in New Guinea, were kinds commonly met with in temperate regions. Some of them were undoubtedly introduced into the instruments during manufacture, by way of the luting wax, cork pads and the lubricant used on screw threads. This could not easily have been avoided, even if manufacturing operations had been carried out in air conditioned rooms (as they sometimes were), since moulds are found almost everywhere—in the air (up to 10,000 feet), in clothing and in soil. Some were introduced later in storage by the "breathing" of the instruments. The small size of the spores of moulds —approximately five thousandths of a millimetre in diameter, would make this comparatively easy.

The growth of moulds on apparently clean surfaces of glass, at first sight so astonishing, was easily explained by the mycologists. Moulds growing on glass derive their initial food from substances stored in the spore (the reproductive body) or from dust or organic debris such as the bodies of dead mites; the water needed is supplied by that which condenses on the glass surface. This moisture film also carries with it the essential traces of mineral salts dissolved from the glass. Etching of glass by moulds growing upon it is probably due to attack by metabolic products of the moulds. Fungal spores can survive a wide range of temperature and degrees of desiccation; their unusually rapid growth in the tropics is almost entirely due to high relative humidities.

To "tropic-proof" an optical instrument meant either finding some way of maintaining the air within it at a relative humidity of below 70 per cent, or, if this could not be done, of keeping the air within continuously sterilised. Perfect sealing after initial drying and sterilisation of an instrument proved a practical impossibility. Another method tried was to place a desiccant within the instrument and then to seal it sufficiently well to allow the desiccant to take care of such moisture as might enter. Both this and the method of continuous internal sterilisation were used, the choice depending on the nature of the instrument to be treated. As a sterilising agent the Americans used Cresatin (meta-cresol acetate), but there were many objections to it. It corroded zinc and zinc alloys, had a blistering effect on a number of lacquers used in optical instruments and caused softening of Canada balsam, widely used as a lens cement.

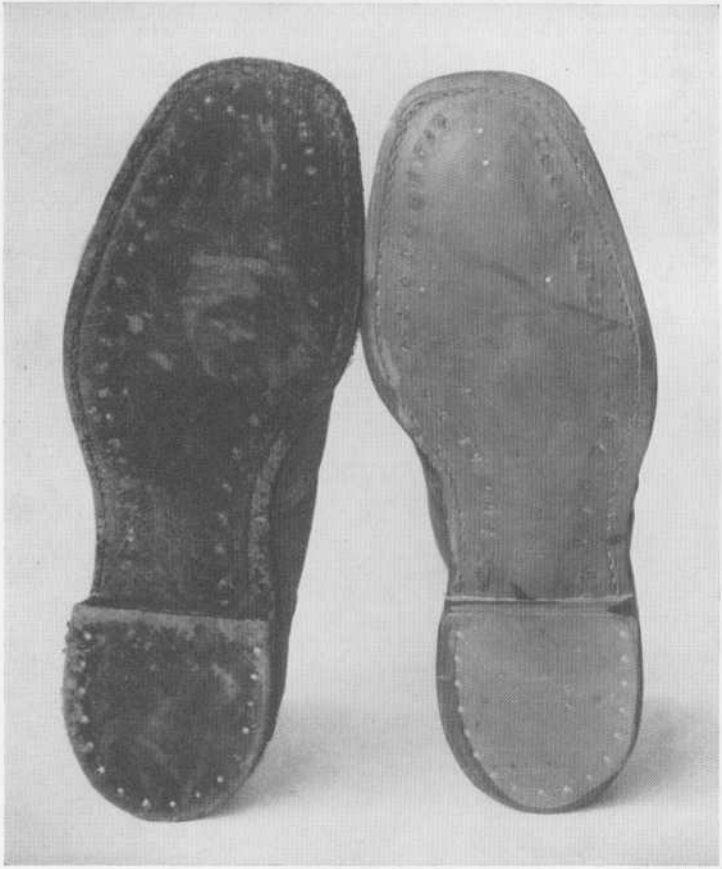
At the suggestion of Professor Trikojus,[4] the Scientific Instrument and Optical Panel investigated the suitability of ethyl mercury thiosalicylate—a fungicide possessing high toxicity at low concentrations, even those produced by its low vapour pressure at ambient temperatures. Tests having

[4] V. M. Trikojus, MSc, DPh. Prof of Biochemistry, Univ of Melbourne, since 1943. B. Sydney, 5 Feb 1902.



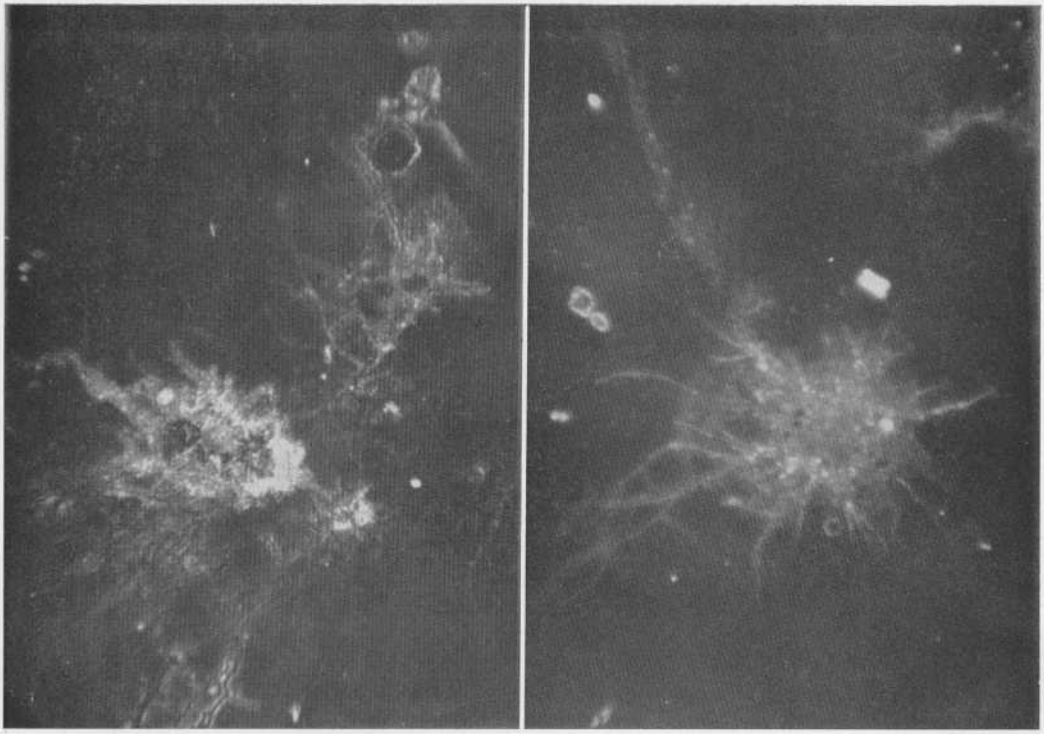
(*A.W.A.*)

Mould growth in field radio set.



(*A.W.A.*)

Mould growth on army boots.



(University of Melbourne)

Binocular prisms etched by fungus. The fungus has all been removed.



(A.W.A.)

Glass solder-sealed capacitor and moulded capacitor from a field wireless set. Mould growth can be seen clearly on the moulded capacitor.

shown considerable success, the Scientific Liaison Bureau sponsored the production of the chemical in large quantities, and under the name of "Merthiosal" or "M.T.S. anti-mould" it was incorporated both in the black lacquer used for painting the internal surfaces of instruments and in the luting cements and waxes. The Australian experience was that M.T.S. anti-mould was easy to apply in the factory, cheaper and a more efficient fungicide than cresatin, did not cause corrosion of metals and alloys and was without any appreciable odour.[5]

That merthiosal did its job efficiently was evident from tests conducted in the laboratory and in the field (at Lae, New Guinea) on treated and untreated binoculars. One of its early applications in the field was in the treatment of 350 cameras for the United States Army Air Force. Favourable reports on the efficiency of the treatment were made by the United States Office of Scientific Research and Development.[6] It was not long before the treatment was adopted by the R.A.A.F. for its cameras; a little later the R.A.F. began to use it. In fact its use became quite widespread in the Royal Navy and the Royal Australian Navy, the Australian Army, Far Eastern Command of the British Forces and the United States Army Air Force.

Aluminium alloys in aircraft cameras suffered considerable corrosion in the tropics. Experiments in Melbourne indicated that, as would be expected, much of this corrosion was caused by moisture, especially salt-laden moisture, and that it could be readily reduced by painting the aluminium with black lacquer. In the early, short-term tests incorporation of merthiosal in the lacquer did not appear to lessen the ability of the lacquer to prevent corrosion, but because merthiosal was an organo-mercury complex, it came under suspicion as being likely to promote the corrosion of metals, especially aluminium. This was the substance of the criticism levelled at Turner's work on merthiosal by Dr J. W. Fay of the British Ministry of Supply.[7] Fay also argued that no proof had been given, in the form of long-term experiments, that the superiority of the method of treatment was in fact due to merthiosal and not merely the result of painting the interior surface of the metal with lacquers. These criticisms were met by experiments carried out in 1947 at the army's request, when 100 pairs of binoculars, of which only one side had been fully tropic proofed, were exposed for periods of up to two years at Lae.[8] The experiments showed that merthiosal incorporated in lacquer was an efficient fungicide over a period of two years in tropical conditions, so long as it was used in binoculars of a well sealed type. In badly sealed instruments it was of very much less value. They also demonstrated that the fungicidal action was due to merthiosal and not to the lacquer alone; further, that

[5] Some American workers thought cresatin was the better fungicide of the two; experiments at Panama, for example, led them to this view.

[6] Reports 6055 and 6218.

[7] J. S. Turner, E. I. McLennan and E. Matthaei, "Tropic Proofing of Optical Instruments", *Nature*, Vol. 158 (1946), p. 469. Fay's criticisms appeared in a comment on this article.

[8] Turner, McLennan and Matthaei, "Tropic Proofing against Fungal Infections in Binoculars", Final Report, Univ of Melb (1951).

there was no corrosion of the metal parts of the binoculars, notwithstanding the incorporation of merthiosal with the lacquer.

The objections raised by the Americans to the use of merthiosal appear to have been based on the fact that they made their tests on badly sealed instruments. Suspicions entertained in Britain about the tendency of merthiosal to cause corrosion probably arose from the fact that lacquers used in Britain differed from those specified for use in Australian instruments. This pointed to the necessity of further work on the question of the suitability of different lacquers for use with merthiosal.

Optical instruments permanently mounted on guns were usually not so much troubled with moulds as with condensation of moisture on the lenses, which blocked vision. This was indeed a serious trouble, and was not confined to any one class of instrument. Very few types of optical instrument were so well sealed as to prevent the ingress of moist tropical air, and once this happened cooling of the instrument was likely to cause condensation. It was quite common to find optical instruments in the tropics in which there was free water. An instrument sufficiently well sealed to leave only a small leak could be kept reasonably dry for a short period by enclosing within it a desiccant such as silica gel. Under service conditions this treatment was only partly successful because it was difficult to renew the desiccant and also the mistake was often made of expecting too much of it.

Another remedy tried was to provide the instrument with a metal carrying-case which could be hermetically sealed. When not in use the instrument was kept in the case together with a desiccant, and could be dried out in this way if necessary. This remedy was never fully tried out in New Guinea. Attention was given overseas to the possibility of finding a transparent material which could be smeared on optical surfaces to prevent the formation of an obscuring film of water. One was proposed by Frankford Arsenal in the United States. Unfortunately the material (D.M.O.-G.T.)—probably a wetting agent which prevented droplet formation by causing condensed moisture to spread as a continuous film—the best discovered up to that time, was effective only for a few days. For this reason its use was not recommended by the Scientific Instrument and Optical Panel. The problem of preventing the condensation of moisture in optical instruments in the tropics was, at the end of the war, still far from solution. Nevertheless, the work of the Scientific Instrument and Optical Panel's Committee on Tropic Proofing was as a whole of great value and was widely recognised overseas by those interested in this aspect of defence work.

One of the serious oversights in the organisation of supplies to the Australian forces in New Guinea was the sending of white tents to the fighting areas. To use a white tent for an isolated radar post in the tropics was simply asking for trouble. Appreciating the dangers involved, the men began painting their tents with whatever materials were at hand —even sump oil. Very soon the tents began to rot and leak. The Scientific

Mission reported that there were 30,000 tents in New Guinea, most of which leaked. The discomfort of the men, the loss of efficiency and the economic losses due to deterioration of the tents, tarpaulins and covers of all kinds, were at this time considerable, and but for early adoption of native thatched huts might well have been quite serious. Camouflage paints were often blamed for the spoilage, but wrongly so if the emulsion paints recommended by the Department of Home Security were used. The real trouble was caused by moulds and mildews, long known as the enemies of canvas in temperate climates; in the tropics they were especially destructive.[9]

In view of the work begun in the Munitions Supply Laboratories early in 1941 on problems of rot proofing canvas,[1] it may seem a little surprising that such trouble should have been experienced with tents in New Guinea. The General Chemistry Section of the laboratories had, in collaboration with Messrs G. Kinnear & Sons (Melbourne), developed the application of the copper creosote treatment to sandbags, "but at this time it was almost impossible to get the army to take any interest in our proposals for the treatment of the millions of unproofed sandbags that had been imported from India".[2] Although a specification had been prepared for and issued by the army, not much progress was made in rot proofing canvas until late in 1942. To further the mycological work, for which the Munitions Supply Laboratories were not equipped, the Chemistry Section enlisted the cooperation of Mr G. C. Wade, Assistant Plant Pathologist of the Burnley Plant Research Laboratories of the Victorian Department of Agriculture, and in the following year rot proofing of canvas began in earnest. The Mycological Panel materially assisted the Munitions Supply Laboratories in this program.

The Scientific Mission had supported the view that all canvas should be rot proofed by the copper oleostearate process, though it was well aware that some fungi could tolerate copper and actually feed on the oleic and stearic acid formed by the breakdown of the copper compound.[3] It suggested that simple inorganic salts should be investigated for fungicidal activity, but in the meantime that salicylanilide be mixed with copper oleostearate to take care of the copper-tolerant species. Later researches in the United States revealed that copper naphthenate was more effective than the oleostearate because the naphthenic acid formed on its breakdown also had fungicidal properties. The Department of Home Security had its own special recipe, which employed a solution of tannin and copper

[9] Though these were the agents mainly responsible for the breakdown of cellulosic fibres, some destruction of the cellulose fibres of the canvas was no doubt caused by bacterial attack as well.

[1] A. B. Cox, W. R. Hindson, K. N. Mortensen, G. C. Wade, "The Treatment of Cellulosic Fabrics and Cordage for Use in Tropical Areas". M.S.L. Report 170, Nov 1945.

[2] Munitions Supply Laboratories, "War History 1939-45", p. 51.

[3] It would probably be more accurate to say that the fungi feed on the products of the hydrolytic breakdown of this substance, namely oleic and stearic acids. Protection with copper salts was offset by the tendency shown by all copper compounds to accelerate the disintegration of cellulosic materials in the presence of light. Disintegration caused by light was less serious than that caused by moulds in the absence of copper salts. Cellulose acetate in the presence of copper salts is less affected by light than cellulose itself.

acetate. Without trying to assess the relative merits of the different processes it is sufficient to record the results as assessed in an army report:

> The considerably improved performance of tentage generally, in tropical areas, and the consequent effect on personnel and stores has been such as to entitle those connected with the developments to a justifiable pride in the success of their efforts.[4]

The life of a tent was on an average increased fourfold by rot proofing,[5] but much work remained to be done on this problem if greater life was required.

No deterioration of the silk in parachutes through mould or bacterial attack was ever observed, though cotton in packs and pack harness was commonly attacked. Artificial silk (rayon) was affected in varying degrees according to the type; acetate rayons were among the most resistant. Nylon, like silk, was immune.

Few metals are found as such in nature; most have to be laboriously extracted from their ores. No sooner are many of them extracted than they begin to revert to their former combinations by a process known as corrosion. Economic losses from corrosion are everywhere enormous, and consequently it has been the subject of countless scientific investigations over many years. Most metals and their alloys undergo corrosion, the speed of which varies greatly according to the physical conditions to which they are subjected.[6] The importance of water vapour in the atmosphere is paramount. So long as the relative humidity of the atmosphere does not rise above a certain critical value, usually in the neighbourhood of 50 to 70 per cent, corrosion takes place only very slowly. High temperatures and humidities combine to accelerate corrosion. For this reason, in the tropics, stores and equipment built of metal or containing metal suffered corrosion to an unusually high degree. Ferrous metals and certain die-cast alloys were among the most seriously affected.

One of the most generally used methods of preventing or at least slowing, corrosion was to coat the metal with a protective film of some kind. The only protective materials provided for in the army *Vocabulary of Stores* up to 1942 were an oil known as Oil A, and conventional lubricating greases. These were effective only in relatively dry climates. Early in the New Guinea campaign the army had solved some of its corrosion problems by the use of suitable paints. Other rust preventives were known to industry, though their importance was not fully appreciated either by the Australian Army or the R.A.A.F. An expert of the Shell Oil Company of Australia[7] seconded to the Munitions Supply Laboratories (later a member of the Scientific Mission) introduced new and more efficient rust preventives such as oils incorporating the naphthenates of zinc and aluminium. Like the great majority of wartime scientific activities, treat-

[4] M.S.L. "War History".

[5] W. R. Hindson and K. N. Mortensen, "Fungicidal Treatment of Textiles, Leather and Other Materials". Circular 12, Defence Research Labs, 1948.

[6] The exceptions include gold, platinum, titanium, zirconium, tantalum and niobium, all of which are far too expensive for any but limited uses.

[7] Mr C. T. Hansen.

ments for the prevention of corrosion merely involved the application of existing scientific knowledge and techniques.

Although the basic components of leather were relatively stable proteins and therefore not susceptible to attack by moulds, most leather goods became very quickly covered with profuse growths in the tropics. The growths, usually sustained by the considerable quantities of fats and oils worked into the leather to make it more pliable, did not affect the leather except to spoil its appearance and to cause much waste of time in the efforts to restore it. Army boots deteriorated rapidly, but for another reason. Owing to the generally wet conditions underfoot in the tropical jungle, iron nails and other grindery underwent rapid corrosion. The first indication of rusting was the appearance of blueing in the leather adjacent to the iron. Rusting itself was not so serious as a secondary effect arising from it: iron compounds formed during corrosion combined with the leather to produce a bluish black material that was brittle and no longer resistant to wear. More than 100,000 pairs of boots in ordnance depots in New Guinea had deteriorated to such an extent that the Scientific Mission considered they would be unlikely to give more than poor service in difficult country. One of the most serious consequences of this deterioration was that the soles and heels very soon pulled off.

Since all other damage was small compared with that caused by the contact of continually moist leather with ferrous grindery, army authorities decided that the use of unprotected ferrous grindery should be discontinued, a decision with which the Scientific Mission concurred.

The greatest losses of foodstuffs in the tropics occurred through the corrosion of cans, which in some instances was extremely severe, both in outdoor dumps and in stocks under cover. Losses were greatest with unlacquered cans containing highly fermentable foods such as fish and meat. At one base storage depot alone the mission noted the complete destruction of 90,000 cans of fish. Unpopular foods, and these included fish, were the worst affected because the cans were left an unusually long period in store. Only about one per cent of the losses of canned goods was due to mechanical causes or to faulty sealing and retorting of cans.

Once moisture formed on a can, corrosion began—usually where the metal had been stressed in processing (at the expansion rings, seams and embossing)—and soon produced a pinhole. Owing to reduced pressure within the can air was then sucked in through the puncture, carrying with it putrefactive bacteria. Gases arising from the fermentation subsequently set up caused blowing and squirting of the contents of the cans. It was found that once about 20 per cent of a stack was affected in this way the whole stack could be written off as a total loss. Hydrogen swells occurred more commonly than in cooler climates but did not cause serious wastage.[8] Unusually thinly coated tinplate, long storage periods and low

[8] These were caused by the formation of hydrogen from the attack of acid juices on the iron of the tinplate.

initial vacuums contributed to the increase in the incidence of hydrogen swells. Application of lacquers to the outside of a can usually extended its life out of doors in the tropics from two months to four or five months. Unusually good corrosion resistance was noted in the Service biscuit tins made from roller-coated tinplate with stoved or pigmented finishes. These survived unharmed in the severest tropical conditions for more than nine months. The Scientific Mission, in drawing attention to this example, urged that further experiments should be made to discover more fully the possibilities of this kind of protection. The air-drying lacquers then in general use were by no means perfect in the protection they gave and the problems of the tropics stimulated a great deal of research both in Australia and in the United States on ways and means of improving the efficiency of lacquers in preventing corrosion.

The work of the Scientific Mission had shown the kinds of problem met with in the tropics and had prompted the scientific investigations to solve them. The next step was to see how far recommendations based on laboratory experience were proving effective in operational areas. After consulting the Services, Cummins suggested to General Blamey that scientists should be permitted to visit forward areas to undertake this assessment. More specifically, he proposed that a tropical scientific section consisting of civilians should be set up and attached to the army, with the proviso that the other Services should receive the benefit of its work and be supplied directly with reports on their own problems; that the Scientific Liaison Bureau should select the scientists, pay their salaries, receive reports and be responsible for coordinating the work. It was considered desirable that the scientists should be changed from time to time to make available to laboratories the experience gained in the field, and also to avoid the fatigue resulting from tropical conditions.

Blamey agreed to the proposal on 31st January 1944, but it was not until 21st May that an Army General Routine Order was issued, followed by similar announcements by the navy and air force on 6th June and 21st August respectively. In the field the Tropical Scientific Section worked under the direction of the Branch of the Master-General of the Ordnance. Scientists were given officer status but no specific rank, which seemed a satisfactory working arrangement.

The section was given the following duties:

(*a*) to advise the responsible Service authorities on the installation or placing in service of any experimental or trial consignments of material in non-active operational areas, and where requested to undertake such installations;

(*b*) to undertake tests, as required by the responsible Service authorities, of new or modified procedures, as for instance the testing of fungicides for optical munitions to determine their suitability for general use;

(*c*) to follow through tests and submit scientific reports as and when necessary;

(*d*) to report upon the effect of tropical conditions on general Service matériel and especially to report upon conditions of unusual deterioration;

(*e*) to assist where possible as advisers to ordnance depots, field workshops and stores depots in so far as prevention of deterioration from tropical effects is concerned.

While it was not proposed that the section should work nearer to the battle area than divisional headquarters, it was intended that it would cooperate closely with the Operational Research Section of the army, which would take care of investigations in forward areas.

The first two members of the section were appointed in May and June 1944 respectively: Dr Consett Davis,[9] as a biologist, and Mr Alexander,[1] as a chemist, both of whom were seconded from the army. They proceeded to operational areas on 8th June in the company of the director of the bureau.

In collaboration with the Inter-Service Committees the section carried out field tests on materials and procedures for tropic proofing. At the request of the Services it made surveys and studies of particular aspects of tropical deterioration of stores and equipment; for this latter purpose additional civilian scientists were occasionally attached temporarily to the section. Thus, following a request to the army by the Institution of Radio Engineers, three representatives of the radio industry became temporary members of the section in order to visit New Guinea for the purpose of studying the performance of radio and signals equipment and its resistance to deterioration in tropical operational areas, and thus of obtaining first-hand knowledge of operation conditions and of the effectiveness of the newer industrial materials and manufacturing methods.

The Scientific Liaison Bureau published some of the results of the section's work in a series of reports, which are listed at the end of the chapter.

All in all, the experience gained by the fighting forces and by Australian scientists in New Guinea led to considerable improvements in the maintenance of war matériel, though the problem as a whole was still far from solved. It is understood that since the war Britain has made considerable use of the information on packaging and tropic proofing in developing her markets in tropical countries. When Australia sets out seriously to develop to the full the potentialities of her sub-tropical and tropical regions and her territories to the north, the wartime experience in overcoming the effects of intensely humid and warm climates should stand her in good stead.

Despite all the efforts of the bureau it is difficult to escape the impression that scientists and engineers within the armed services wasted a good deal of time rediscovering old knowledge. This was not because there were no central repositories of technical information; the Patents Office, universities, and many government instrumentalities, such as the C.S.I.R., all possessed libraries. The difficulty was that this technical information had not been organised in such a way as to be readily accessible to the armed services. This could have been remedied by giving the Scientific

[9] Lt H. F. Consett Davis, DSc. Lecturer in Biology, New England Univ College, NSW, 1939-41; P-O RAAF 1940; instructor in Tank Corps 1943; member Scientific Liaison Bureau 1943-44. Of Sydney; b. Sydney, 23 Jun 1913. Killed in aircraft accident in New Guinea 11 Dec 1944.

[1] Maj M. R. Alexander. AAOC 1941-42; AEME 1942-45; seconded Tropical Scientific Section MGO Branch 1944-45. Engineer; of Longueville, NSW; b. London, 14 Aug 1911.

Liaison Bureau the support and status that the Armed Services Technical Information Agency enjoyed in the United States.

REPORTS OF THE TROPICAL SCIENTIFIC SECTION

D. J. O'D. Davis, "The Effect of Tropical Storage Conditions on Ammunition and Explosives".

E. Troughton, "A Review of Field Investigations Concerning the Mammal Reservoirs of Scrub Typhus in the New Guinea Area" (1945).

E. W. Hicks, J. F. Kefford and H. S. McKee (CSIR), "Report on Food Stores in New Guinea".

A. N. Swinfield, "Report on Investigations Regarding Performance, Maintenance and Repairs of all Watercraft in Operational Areas".

A. W. Shillinglaw, D. D. Moore, "Report on Marine Borer Survey in New Guinea Waters".

C. S. Gittoes, D. W. Rowed and R. J. Collins, "Report on Deterioration of Telecommunications. Radio Mission of the Institution of Radio Engineers, Australia."

CHAPTER 25

FOOD

NO other industry occupies such a large share of the energy of mankind as does the production, transportation, processing and marketing of food. The food industry is the foundation alike of social security and economic prosperity. In Australia, just before the war, approximately 500,000 people were engaged in rural production alone, but as a result of enlistments and movements of large numbers of men and women into munition factories, where wages were higher, this number was reduced during the war to 380,000 at its lowest ebb. Faced with difficulties of transport and shortages of machinery and fertilisers (especially of superphosphate after Ocean and Nauru Islands had been captured by the Japanese), and overwhelmed with one of the worst droughts in its history, the food industry had to meet its greatest challenge in the latter part of the second world war. Australia was required to produce enough food, over and above the needs of her own population, to meet practically all the needs of the Allied forces in the South-West Pacific.

The part that Australia might be expected to play in providing foodstuffs for the United Kingdom in the event of war was discussed during 1938 with the British Food (Defence Plans) Department, when agreements were reached under which the British Government undertook to buy Australia's exportable surpluses of foodstuffs, including grain and dried and canned fruit. After war broke out and submarine warfare made it imperative to exercise the strictest economy in the use of shipping, these earlier agreements had to be modified by introducing a policy of exporting only the more concentrated forms of food, such as butter, cheese, eggs and meat, leaving countries much nearer to Britain to supply the more bulky foods such as grains and canned fruit. So acute was the shortage of shipping that even with these modifications to export policy some foodstuffs began to accumulate in Australia to an unusual extent. The main effect of the outbreak of war was to raise problems of surplus production.[1] These problems, which were generally of an economic character, being concerned with ways of protecting the primary producer against the collapse of the market, caused the Commonwealth Government through the Department of Commerce to assume control of oversea food marketing. This story is told in another volume of this series.[2]

Typical of the technical problems of the era of surplus foodstuffs were those relating to their storage.[3] The work done on problems associated with

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[1] *Commonwealth Year Book*, Vol. 35 (1942-43), p. 921.

[2] S. J. Butlin, *War Economy 1939-42*.

[3] Enormous quantities of wool also had to be held in store during the war and similar problems had to be faced with it. The common clothes moth was the chief offender, but fortunately it limited its depredations to the outer 2 inches of the bale. Effective control was obtained by spraying the outside of the bales with special oil sprays: Middle Oil 43, a tar oil, for greasy wool, and a saturated solution of naphthalene in orthodichlorobenzene for scoured wool.

the storage of wheat is an excellent example of the application of science to this field, and for this reason it will be discussed in some detail.

As a consequence of the policy withholding the export of wheat, Australia was confronted with the serious problem of preventing the deterioration, through the attack of insects, of the vast quantities of wheat which, owing to the bumper crop in 1939-40, were beginning to accumulate in many parts of the Commonwealth. No one knew how long such wheat would have to be stored, or how much more valuable to Australia and the Allies the surplus wheat might become during or after the war, and with the memory of the devastating plague of weevils and mice experienced in wheat stored in Australia during the first world war it was feared that once again there might be great losses. The campaign carried out in 1917 and 1918 to preserve wheat from destruction was described as "the greatest battle man has had to fight against stored grain pests anywhere and at any time". A truly alarming number of victories went to *Calandra oryzae* and *Mus musculus,* the weevil and the common mouse respectively.[4]

In 1939 there were prospects of an even greater battle against these pests. Although some progress had been made in the control of grain-eating insects during the years 1917-18, no really satisfactory method had been evolved. One of the most promising methods at that time depended on the hermetic sealing of wheat. Under these conditions the respiration of infesting weevils and, to a small extent, of the grain itself, removed oxygen from the enclosed air, replacing it with carbon dioxide, until the insects died by asphyxiation. This method could be applied with relative ease to small quantities of wheat, as had been done by the Egyptians several thousand years before, but its successful application on a large scale (to millions of bushels) was quite another matter. Enclosure of large quantities of wheat in airtight stores was not attempted in Australia until after the war.[5]

Up to the end of the 1914-18 war all wheat had been stored in bags. Since that time more economical methods of handling and storage, intended for short periods only, had been introduced, principally in New South Wales, Western Australia and Victoria. The wheat was held in single masses, which were either relatively small (in the case of silos, temporary bulkheads or bins) or else very large, as in longer-term storage depots where they amounted to as much as 10,000,000 bushels. The essence of the problem presented by wartime conditions was to devise methods of storing wheat on a large scale and preserving it for much longer periods than was customary in peace time. This had not been successfully achieved for stacks of bagged wheat in the first world war

[4] The insect pests mainly responsible for the destruction of wheat are the grain weevils, *Calandra oryzae* and *Calandra granaria,* and the lesser grain borer *Rhizopertha dominica.* The last-named was particularly destructive in Australia during the first world war. Insects, moulds (bin scald), and rodents (mainly mice) also caused destruction.

[5] F. N. Ratcliffe, F. J. Gay and J. S. Fitzgerald, "Wheat Weevils and their Control. A Summary of Existing Information." *Journal of the CSIR,* Vol. 13 (1940), p. 229. Airtight storage was tried in Argentina on a small scale in 1942. The first successful large-scale storage of this kind was carried out in that country in 1948.

and the method of bulk storage developed since then seemed likely to present new problems.

The gravity of the situation was appreciated by the Australian Wheat Board, the body responsible for the storage of wheat, and when signs of serious trouble began to appear in Western Australia (where bulk storage was the general rule) the board approached the C.S.I.R. for help. The Division of Economic Entomology—one of the first divisions to be formed by the council—had been established to assist the farmer in his endless struggle against insect pests, and since 1926 it had been pursuing long-term researches with this end in view.[6] It was therefore in a good position to attack the biological problems involved. Two of its officers, Messrs Ratcliffe[7] and Gay,[8] were deputed to cooperate with entomologists of the State departments of agriculture and to report on the problem as a whole. Infestation of bulk depots in Western Australia was so bad that Ratcliffe and Gay seriously considered recommending their abolition, but bags were so scarce that there was no alternative. The huge mound of wheat in the largest of these depots, which was about a third of a mile long, 200 feet wide and 40 feet high, was described as one vast incubator for weevils.

The problem of protecting stored wheat had been studied in many countries for many years, with results that were often contradictory and confusing, and which did little to allay the anxieties of Australian entomologists entrusted with the task of devising measures for protecting what eventually amounted to some 200,000,000 bushels of wheat, much of it in areas where the climate was more conducive to the development of weevils than in most other wheat-growing areas of the world. In the warm moist climate of Queensland and parts of Western Australia it was practically impossible to store wheat safely for long periods. Many entomologists worked on problems associated with the infestation of wheat by insect pests, but it is probably fair to say that the leading part was taken by Gay and Wilson,[9] who carried on Ratcliffe's work from 1942 when he joined the army as an entomologist.

A detailed study of wheat mounds in the Western Australian bulk depots revealed a very interesting, and in many ways fortunate, state of affairs. Weevils were restricted mainly to the outer layers; below a depth of about a foot there was practically no damage. When Ratcliffe and Gay submitted their report, in June 1940, it was not known whether the heat which often developed in stored wheat was due to the respiration of the wheat itself, to the activities of infesting insects, or to a combination of these

[6] Dr R. J. Tillyard was the first chief of the division. He was succeeded in 1936 by Dr A. J. Nicholson.

[7] Maj F. N. Ratcliffe, OBE. DAD Hygiene, Pathology and Entomology 1943-45; Officer-in-Charge Wildlife Survey Section, CSIRO; author of *Flying Fox and Drifting Sand* (1938). B. London, 11 Jan 1904.

[8] F. J. Gay, DSc. Research Officer, Division of Entomology, CSIRO. Of Canberra; b. Wellington, NZ, 19 Aug 1910.

[9] F. Wilson. CSIR Research Officer in Europe before 1939; liaison officer between CSIRO and Australian Wheat Board; research officer CSIRO Division of Entomology. Of London; b. London, 16 Jun 1907.

factors. Late in 1940 Dr Robertson[1] and Mrs Milthorpe[2] of the Botany Department in the University of Sydney, were asked by the C.S.I.R. to study this problem. They were able to demonstrate that, provided the moisture content did not rise above 12 per cent (Australian wheats averaged about 9.8 per cent) the normal respiration of wheat was insufficient to cause the rise in temperature often noted in stored wheat. They therefore concluded that the rise in temperature was due almost entirely to the activities of infesting insects, chiefly weevils.[3] This conclusion was verified by calculations based on the insects' rate of oxygen consumption.[4]

Although in 1940 the entomologists had a rough idea of the limits of temperature and humidity within which weevils could survive and multiply, it was evident that further information on the subject was required. A more exact determination of these limits was made by Dr Birch[5] of the Waite Agricultural Research Institute, Adelaide.[6] His findings suggested the reason why the attack of weevils on large mounds of wheat was confined to relatively shallow surface layers. As the temperature within a mound rose, the relative humidity of the air within the same zone fell, as also did the moisture content of the wheat, until a condition was reached when weevils could no longer survive. Near the surface of a mound the temperature was lower than at the heart because heat generated by the weevils was readily dissipated by atmospheric convection. In this outer layer alone weevils could flourish. Since the volume of the superficial portion of a mound was small compared with the total bulk, losses sustained by this method of storage were relatively low. The problem of reducing them still further was therefore one of protecting a layer about a foot deep. Sources of infestation were removed by two methods: by spot fumigation with carbon disulphide of areas where weevil appeared, and by treatment of the whole surface of a mound with inert mineral dusts. The former method was used almost exclusively in the bulk depots of Western Australia; the latter, and much more effective, method was used in Victoria towards the end of the war.

Small-scale experiments made in England and other parts of the world some years before the war had demonstrated that weevils could be destroyed by inert[7] mineral dusts, which owed their lethal action to the fact that by abrasion they wore holes in the protective wax layer of the insect's cuticle, thereby increasing the rate of water loss and so killing

[1] R. N. Robertson, PhD. Lecturer in Botany, Univ of Sydney, 1939-46. Of Sydney; b. Melbourne, 29 Sep 1913.

[2] Joan Milthorpe, BSc. C'wealth Research Scholar in Dept of Botany, Univ of Sydney. B. Bangalow, NSW.

[3] R. N. Robertson and Joan Milthorpe, "Heating in Stored Wheat", *CSIR Bulletin* No. 236 (1948).

[4] L. C. Birch, *Journal of the Institute of Agricultural Science*, Vol. 12 (1-2) (1946).

[5] L. C. Birch, BAgSc, DSc. Research entomologist, Waite Agric Research Institute, Univ of Adelaide, 1939-46. Of Melbourne; b. Melbourne, 2 Feb 1918.

[6] L. C. Birch, "A Contribution to the Ecology of *Calandra oryzae L.* and *Rhizopertha dominica fab.* (*Coleoptera*) in Stored Wheat", *Transactions of the Royal Society of SA*, Vol. 69 (1) (1945).

[7] Inert in the sense that they were chemically unreactive and insoluble in water. Investigations showed that the efficacy of these dusts was greatly increased by the addition of small amounts of DDT.

the insect by desiccation. As a general rule the more abrasive the dust the more effective it was. Disinclination overseas towards the widespread adoption of this method was due to the health hazards that might be involved in its application. Such considerations did not deter Australian investigators; the potentialities of inert mineral dusts as a means of preventing the attack of weevils on wheat in bulk stores were quickly realised and a search was promptly made for suitable dusts among materials of local origin.

After testing many materials Dr Fitzgerald[8] came to the conclusion that magnesite from Tullamore (New South Wales) and dolomite from Coimadai (Victoria) were the most promising.[9] Neither of these substances was particularly hard or abrasive, but they were effective and their use received the sanction of the Commonwealth Department of Health. Towards the end of the war these dusts were given a large-scale trial, the first of its kind, on some 16,000,000 bushels of wheat in the bulk depot at Murtoa.[1] By the combined use of spot-surface fumigation with carbon disulphide and the application of inert mineral dusts to the outer layer of a mound, it was found possible to store bulk wheat at Murtoa for about three years without serious damage.[2] This was a notable technical advance in the bulk storage of wheat.

Protection of bagged wheat, which made up a substantial proportion of the wheat stored, was a little more complex in so far as it was also necessary to guard against the ravages of mice. Much of the trouble experienced in storing wheat during the first world war arose from the fact that mice not only ate the wheat but destroyed the bags, causing wheat to spill from stacks. Mice were not a serious menace to wheat in bulk stores since they were not able to nest and breed in the mounds to any important extent. Once precautions had been taken to prevent their entrance into sacks of bagged wheat, the problem of protection was reduced to finding a suitable fumigant against weevils and an appropriate method of applying it on a large scale. Of the readily available substances carbon disulphide once again proved the most suitable fumigant. That, in spite of the explosive and toxic nature of its vapour, carbon disulphide was used in large quantities on bag stacks—up to 1,700 gallons in one application—without mishap, is a tribute to the courage, organisation and care of the fumigators.

During the war as much as 90,000 bushels were treated as a single unit, and altogether several millions of bushels of bagged wheat were protected by this method in Victoria and South Australia. Some of this wheat was stored for three or four years without damage. This also

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[8] J. S. Fitzgerald, PhD. Research officer, CSIR Division of Economic Entomology, 1936-41, Division of Industrial Chemistry since 1941. B. Auckland, NZ, 23 Apr 1909.

[9] J. S. Fitzgerald, "The Effectiveness of Various Mineral Dusts for the Control of Grain Pests", *CSIR Bulletin* No. 182 (1944).
F. Wilson, "The Use of Mineral Dusts for the Control of Wheat Pests", *CSIR Bulletin* No. 199 (1946).

[1] F. Wilson, "Wheat in a Victorian Bulk Depot", *CSIRO Bulletin* No. 244 (1949).

[2] After the war the efficacy of mineral dusts was greatly enhanced by mixing them with hexa chlorocyclohexane (666 or B.H.C.).

represented a notable technical advance in the large-scale application of protective methods to the storage of wheat. On the whole, hygienic measures adopted in large depots of both kinds (bulk and bags) were so effective that the shortage of transport to the depots was probably the greatest menace to the safety of the huge quantities of wheat handled and stored during the war years. Temporary storage depots—poorly constructed and unsuitably placed—were additional menaces.

Scientists' victories over insect pests were never complete. In spite of all precautions a few weevil outbreaks did occur and cause some concern, but they were at no time as serious as those of the 1914-18 war. Huge quantities of wheat amounting to 200,000,000 bushels were stored with insignificant losses. It was by no means a negative victory. With the safety of large stocks of wheat assured it was possible, when the need arose in 1942, to transfer much of the manpower, machinery and fertilisers previously used for growing wheat to the production of urgently needed vegetables.[3]

While entomologists were preoccupied with the problems of storing wheat, medical scientists directed their efforts towards discovering whether the Australian population was being supplied with adequate diets—in particular whether diets were sufficiently high in vitamin B1 according to standards set down by authorities on nutrition. The Australian investigation was touched off by the announcement in July 1940 by the British Ministry of Food that it had decided to fortify wheat flour for bread with synthetic vitamin B1 and calcium and that a factory was being built for the manufacture of vitamin B1. The Federal Council of the Flour Mill Owners of Australia, apparently without any better reason than that the British authorities were doing it, strongly supported the idea that the Commonwealth should do something similar. Fortifying flour in this manner was bound to be very costly and could be justified only if it were shown that Australian diets were seriously deficient in this vitamin. When the question was put to the Nutrition Committee of the National Health and Medical Research Council it replied that there was no evidence to show whether the diet of Australians was even partly deficient in vitamin B1 or whether any condition of disease attributable to such a lack existed among Australians.[4] Obviously the first step was to find answers to these

[3] The work proved valuable when in peace time market prospects were uncertain, and the knowledge of how to store wheat for long periods was again useful.

[4] Report of National Health and Medical Research Council, 12th Session, held at Canberra in 1941. Nos. 26 and 27. Appendix II, pp. 44-77.
A body known as the Advisory Council on Nutrition was set up by the Commonwealth Government in 1936 to investigate the state of nutrition of the Australian people. It was reconstituted as a committee of the National Health and Medical Research Council and held its first meeting in Canberra in January 1939. Its membership was: Dr F. W. Clements (Chairman), Senior Medical Officer, Commonwealth Dept of Health, and Director, Aust Institute of Anatomy; Professor Sir Stanton Hicks, Dept of Pharmacology and Human Physiology, Univ of Adelaide; Prof H. Priestley, Dept of Biochemistry, Univ of Sydney; Prof D. H. K. Lee, Dept of Physiology, Univ of Queensland; Prof S. M. Wadham, Dept of Agriculture, Univ of Melbourne; Prof H. R. Seddon, Dept of Veterinary Science, Univ of Queensland, and later Officer-in-Charge of the Food Section, Rationing Commssn, Melbourne; Dr Ivan Maxwell, Lecturer in Clinical Biochemistry, Univ of Melbourne; Dr E. J. Underwood, Institute of Agriculture, Univ of Western Australia; Dr C. L. Park, Director of Child and Maternal Welfare and School Medical Services, Tasmania; Miss Joan Woodhill, Dietitian, Royal Prince Alfred Hospital, Sydney.

questions, and with funds provided by the National Health and Medical Research Council, the Federal Council of Flour Mill Owners of Australia and the Rural Bank, the Nutrition Committee set to work to make a survey.

From an examination of Australian wheats and flours made by a staff of chemists working at the Australian Institute of Anatomy at Canberra and in the Biochemistry Department of the University of Melbourne, came the reassuring finding that the vitamin B1 content compared more than favourably with that of wheats and flours examined in Britain and in the United States, as can be seen from the accompanying table.[5] Some

Country of origin	Vitamin B content in international units per lb	
	Wheat	Flour
Australia[6] . .	760	235-270
Great Britain .	590	138-159
United States .	680	77

varieties of Australian wheat, such as Dundee, Pusa and Ford, were found to be distinctly richer in vitamin B1 than others. The locality in which the wheat was grown also appeared to have an important influence on its vitamin B1 content. Wheat grown in the Mallee areas of both Victoria and South Australia was richer in the vitamin than the same varieties grown elsewhere.

The average Australian diet, which comprised other sources of the vitamin than bread, was calculated to contain about 300 international units of vitamin B1 per person per day, a figure that was confirmed by direct determinations made on diets of members of the armed forces. This figure was very similar to that found for wage earners and clerical workers in a number of American cities (330 international units) and fell within the range of what was at that time considered a desirable intake (245 to 326 international units). This is not to say that all elements of the Australian population received adequate vitamin B1, but the average was a satisfactory one.

On the strength of these findings the Nutrition Committee refrained from recommending that wheat flour should be fortified with added vitamin substances. Only the most convincing evidence could have justified the addition of an expensive synthetic product to replace one that had been removed by milling. These studies were by no means as fruitless as this negative result might suggest: they increased knowledge of the quality of an important foodstuff, and gave chemists experience in developing the most up-to-date methods of assaying foods for the vitamin B1 content—experience which was turned to good account during 1941 in making surveys of the state of vitamin B1 nutrition of servicemen in training. Further surveys were planned but were abandoned after Japan entered the war because of the diversion of chemists to more urgent problems.

[5] F. W. Clements, "Australian Activities in the Field of Human Nutrition", *Australian Journal of Science*, Supplement to Vol. 7, No. 6, 21 Jun 1945.

[6] Later work by Dr R. A. Bottomley has shown that these figures are rather too high.

Although the exact function of vitamin B1 was not then known there was some evidence that it was concerned with metabolism of carbohydrates and possibly proteins, and that for the maintenance of health more was required in tropical than in temperate climates.[7] For this reason army medical authorities were greatly concerned to see that the men in New Guinea and other Pacific islands should receive adequate quantities of this vitamin, and steps were taken to fortify bread by adding wheat germ.[8]

As armies have grown in size, feeding them efficiently has become a more and more complex problem. Warfare in the South-West Pacific Area during 1942-45 added another complexity—that of adequately feeding armies in tropical climates and under adverse physical conditions in jungles. This was to constitute one of the main problems of the wartime food-processing industries.[9]

In the pre-war years the Service which paid most attention to food was the navy, which under the necessity of continually maintaining supplies to its ships, had developed an efficient and highly organised Victualling Department, operating according to principles and specifications laid down by the British Admiralty.[1] As a means of checking food specifications under which its purchases were made, the Navy Victualling Department maintained a properly equipped laboratory in Melbourne. Until the second world war the navy was the only member of the defence services in Australia to do this. On the other hand, the army, even after war broke out and although its numbers were greater than those of the other two Services, did not have a single quality-control officer attached to its staff.

The scale of rations for the Australian Army had for a long time been determined largely by considerations of energy requirements, and was such that the average diet—comprising carbohydrates, fats and proteins in amounts and proportions worked out by physiologists and biochemists in Britain a few years before the outbreak of the first world war—provided about 4,000 calories. During the period between the wars little attention had been paid to the application of the newer knowledge of nutrition to the problems of feeding troops, so that with some notable exceptions army officers were not greatly concerned with nutrition as a means of maintaining stamina and morale.[2]

As might be expected the importance of nutrition was more fully recognised by the Army Medical Services, and on the outbreak of war it became the responsibility of Colonel Kellaway,[3] as Director of Hygiene,

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[7] Dried yeast fortified with vitamin B as an easy way of incorporating it in dough was supplied to the U.S. Army by Mauri Bros and Thomson, Waterloo, NSW.

[8] Its description in the propaganda literature to the troops as the "morale" vitamin was scarcely a scientific one.

[9] In writing this section I have made considerable use of a thesis by Professor Sir Stanton Hicks entitled "Feeding the Soldier".

[1] Mr C. Massey was Director of Navy Victualling. He was also Chairman of the Defence Services Foodstuffs Committee.

[2] Stanton Hicks.

[3] Brig C. H. Kellaway, MC; FRS, MD, MS. (Served 1st AIF.) Director of Walter and Eliza Hall Institute of Research in Pathology and Medicine 1923-44; Director of Hygiene AHQ 1927-31 and 1939-40; Director of Pathology AHQ 1940-42; Director-in-Chief, Wellcome Research Laboratories, London, 1944-52. B. Melbourne, 16 Jan 1889. Died 12 Dec 1952.

to advise the Quartermaster-General on problems of rationing. Civilians from the catering trade advised him on the economical use and preparation of the ration from the commodities supplied.

Early in the war an important change was made when the function of advising on nutrition was transferred from the Medical Directorate to the Supply Services of the army. Sir Stanton Hicks,[4] Professor of Human Physiology and Pharmacology at the University of Adelaide, was at Kellaway's instigation given the task of advising the Supply Services. Stanton Hicks, a man of great drive and enthusiasm, with a background of experience wider than the practice of medicine (he had at one time been an industrial chemist and later a land surveyor), began to campaign for a more thorough-going application of scientific principles to the feeding of troops. His main theme was that the health, stamina and morale of the soldier were in no small measure dependent on his being properly fed, which in turn depended on the methodical control of the storage, preparation and cooking of food. One of his earliest tasks was to examine ration scales of the Australian Army in the light of well-established scientific criteria. He found that diets contained an excessive amount of fat and meat but were deficient in vegetables and fruit. A similar defect had been discovered in the course of a survey of the diets of 1,800 families in Australian capital cities made in 1936 by the Commonwealth Advisory Council on Nutrition. The survey revealed that though most families got enough energy-rich foods, they did not get enough of the protective foods (fruit, vegetables and dairy products) which provide the accessory food factors—the vitamins—that are essential for growth and well-being. To some extent the dietary defects discovered in the civilian survey reflected the influence of national food habits, though of course the fact that protective foods were more expensive also militated against their extensive use. That the service rations were similarly deficient was not due to economic factors or national food habits so much as to a failure on the part of administrators to appreciate fully the importance of established principles of nutrition.

The particular aspect of the problem to which Stanton Hicks addressed himself was "the final and essential stage in the flow of food supplies, namely their conversion into meals in a palatable and desirable form such that the soldier will ingest them with a minimum of waste".

During the early part of the war when food was abundant the scale of rations for the Australian Military Forces covered some forty items. In the opinion of Stanton Hicks the generosity of this ration was due more to such political considerations as the need to increase the popularity of military training than to scientific principles of adequate nutrition. The results of this policy were almost inevitable. Wastage of food in army

[4] Brig Sir C. Stanton Hicks. (Served 1st NZEF.) 2nd AIF: 1940-46. Dir of Army Catering LHQ; founded Aust Catering Corps. Prof of Human Physiology and Pharmacology, Univ of Adelaide, since 1926. B. Otago, NZ, 2 Jun 1892.

camps grew to such proportions as to constitute a public scandal, which was thoroughly aired in Parliament, in the press and on the radio. It soon became imperative to find some solution to this problem, which was less an economic than a scientific and technical one; in essence it was to improve the use made of the ration. How this was achieved will be told in a later section.

With the entry of Japan into the war the position in regard to food supplies underwent a radical change. The expansion of Australia's defence forces and the arrival of large numbers of American servicemen in the South-West Pacific Area meant that greatly increased supplies of food were required in Australia itself, especially in the sparsely inhabited northern regions and in the nearby islands. At the same time there was no diminution in Britain's needs. For the first two years of the war there had been a tendency to regard the food industry as "expendable". Labour supplies in the rural industries had been allowed to fall by more than 20 per cent and little attention had been paid to maintaining stocks of agricultural machinery, manufacturers of which had been diverting their energies to making munitions. From an era of food surpluses the country began to drift into an era of shortages and confusion. Instead of feeding between 7,000,000 and 8,000,000 people, Australia now found herself committed to attempting what has been estimated as roughly equivalent to feeding between 12,000,000 and 13,000,000 people.

It would be beyond the scope of this volume to attempt to disentangle all the moves and countermoves made in an effort to organise the production, processing and distribution of food on sound lines under a central authority armed with sufficient power to direct all other organisations concerned with any of these activities. The two departments competing for this power were Supply and Commerce. Supply had to this time been concerned with procuring food for the Services; Commerce with the export of food and foodstuffs. Neither department had a clearly defined responsibility for production, processing and distribution.

A number of weaknesses in the food industry were apparent to United States Army authorities soon after their arrival in Australia. They were worried by the absence of mechanical devices for harvesting vegetable crops and of adequate supervision of food canning. They lacked confidence in some of the previously-inexperienced manufacturers who had been given contracts for the canning of non-acid vegetables, and for a time they were far from certain that the inspectors from the Department of Commerce, who were responsible for supervising the canning, would enforce the standards of quality required by the American Army. These were only temporary difficulties, but they all helped to bring the situation to a head. Food had now assumed an importance equal to that of munitions; in fact it had been officially declared to be a munition of war. In other words, the food industry had become a war industry. The requirements of the

American forces for food were so great that for a time they jeopardised supplies to Australian servicemen and civilians.

Forced by the sheer weight of circumstances, the Government at last (in May 1943) set up within the Department of Commerce a coherent administrative organisation for the national control of food: Commonwealth Food Control. This body was given power under the National Security Regulations "to ensure for the purposes of the defence of the Commonwealth and the effective prosecution of the war that adequate foodstuffs, fertilisers and fodder were made and maintained, and to that end to control the growing, production, manufacture, processing, distribution, disposal, use and consumption of food, foodstuffs, fertilisers and fodder". The general policies laid down by the Production and Food Executives of the War Cabinet were implemented by the Controller-General of Food, Mr Murphy,[5] who was in charge of Commonwealth Food Control. Under Murphy came Mr Bulcock,[6] Director-General of Agriculture, and Mr Massey,[7] Director-General of Food Supply. Directly responsible to Massey were the Directors of Service Foodstuffs (Mr Richards[8]), Civilian Food Distribution (Mr Critchley[9]), Food Manufacture (Mr Arnott[1]) and Finance (Mr Hewson[2]), as is shown in the accompanying chart. None of these activities—not even the section of technology within the directorate of food manufacture—was new at the time of the institution of Commonwealth Food Control. The change in administration was one towards greater coordination and rationalisation of the food industry. Commonwealth Food Control did for primary industry roughly what the formation of the Department of Munitions had done three years earlier for secondary industry. Murphy was given powers over primary industry analogous to those possessed by Essington Lewis over secondary industry. The new organisation soon won the confidence of American authorities, who were now content to leave it to supervise and control the procurement of food in Australia for their forces. By lending the services of a number of its technical officers the American Army did much to overcome the acute shortage of food technologists in Australia.

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[5] J. F. Murphy, CMG. Secretary Dept of Commerce 1934-45; Controller-Gen of Food 1943-45; Chairman, Aust Wool Realisation Commission, 1945-49. B. Carlton, Vic, 12 Mar 1893. Died 18 Jan 1949.

[6] Hon F. W. Bulcock. MLA, Qld, 1919-42; Minister for Agriculture 1932-42; member Royal Agricultural Society, England; C'wealth Dir-Gen of Agriculture. B. Mt Arapiles, Vic, 6 Jun 1894.

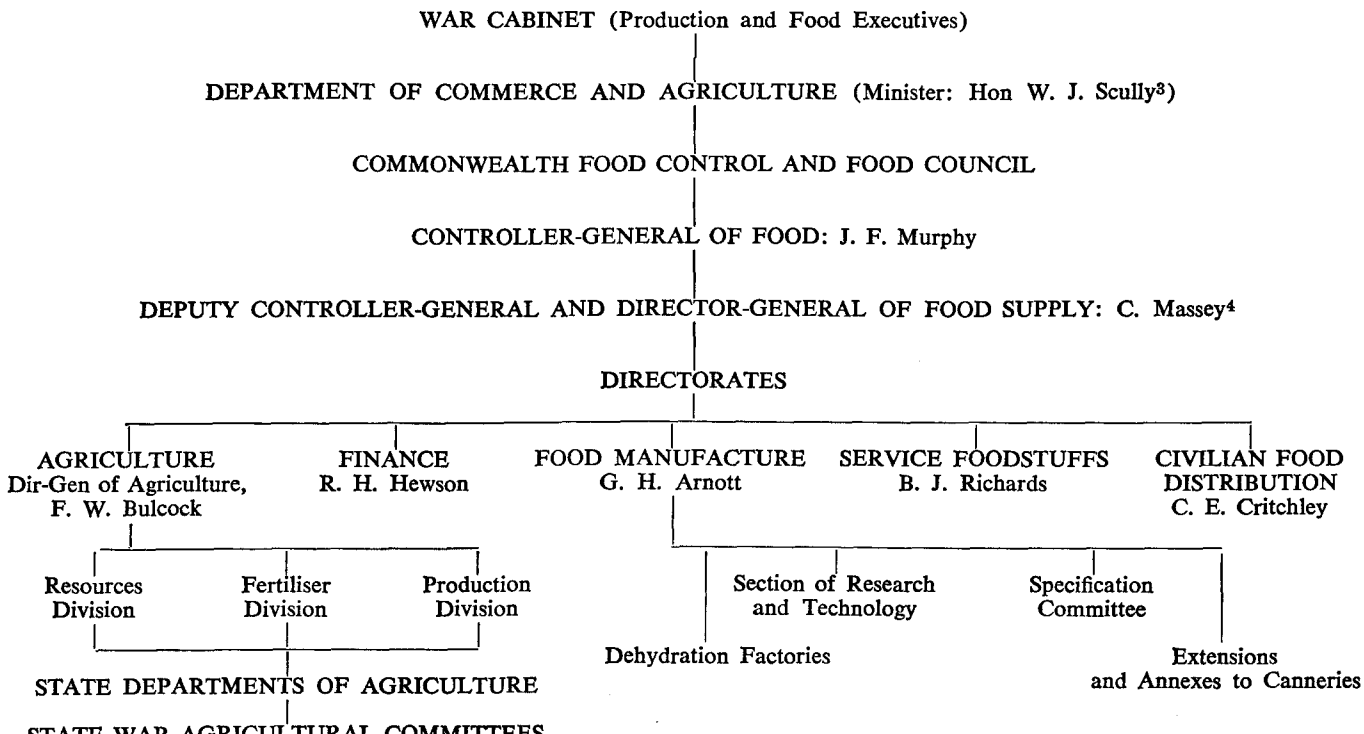
[7] C. Massey. Dir of Victualling for RAN 1926-28; Chairman Defence Services Foodstuffs Cttee 1938; Dep Controller-Gen of Food 1943-46; Aust Minister to Egypt 1949-52. B. Footscray, Vic, 31 Oct 1889.

[8] B. J. Richards. Officer-in-Charge Provision Section, Contract Board, 1939; Acting Secretary, District Contract Board, Sydney, 1941; Director of Service Foodstuffs, Dept of Commerce, 1943. Of Guildford, WA; b. Tasmania, 20 Dec 1885. Died 18 Jun 1952.

[9] C. E. Critchley, OBE, B Com. (Served 1st AIF.) Aust Trade Commissioner NZ 1937-41; Assistant Controller-General of Food 1943-46. B. Melbourne, 21 Oct 1891.

[1] G. H. Arnott. Managing Director Wm Arnott Pty Ltd. Director of Food Manufacture 1943-46. Of Sydney; b. 4 Sep 1902.

[2] R. H. Hewson, BA. Chief Accountant, Dept of Commerce and Agriculture, 1939-42; Govt Finance Member, Aust Apple and Pear Marketing Board, 1942-53; Chief Finance and Administrative Officer, C'wealth Food Control, 1943-46. Of Canberra; b. Melbourne, 4 Aug 1893.



[3] Hon W. J. Scully. MLA NSW 1927-37; MHR 1937-49; Min for Commerce and Agriculture 1941-46. Of West Tamworth, NSW; b. Bective, NSW, 1 Feb 1890.

[4] Until 1944 when G. J. Evatt took over.

PRODUCTION OF VEGETABLES

One of the most notable changes that came over the agricultural scene in 1942 was the great increase in the area devoted to growing vegetables, especially potatoes, cabbages, peas, tomatoes, carrots and beetroot, for processing—that is for canning and dehydration. Only by such methods of preservation was it possible to supply nutritious vegetables to the Services in tropical areas. Australia had previously grown enough vegetables to meet domestic requirements but practically none for export. Additional requirements for the fighting forces had therefore to be obtained from new growing areas. The great increase in production of vegetables was to some extent a reflection of the fact that American troops, of whom there were in 1942 about 100,000 in Australia and New Guinea, were accustomed to larger amounts of vegetables and fresh fruits, especially fruit juices, in their diets than were Australians.

Many difficulties had to be overcome before this great expansion in the production of vegetable crops was achieved, one of the foremost being that of securing adequate supplies of vegetable seeds. Before the war most vegetable seeds had been imported from Europe, the United States, Japan and New Zealand.[5] By the time Japan entered the war practically all sources were cut off except limited supplies from New Zealand and the United States. Stocks of seeds held in Australia were low in 1942 and the position as revealed by a survey made by Dr McMillan[6] of the C.S.I.R. was so serious that the Department of Commerce and Agriculture set up a Vegetable Seeds Committee to go into the question.[7] The responsibilities of the committee were to ensure (*a*) adequate supplies of vegetable seeds in Australia for both defence and civilian needs, (*b*) the use of suitable strains for seed production, and (*c*) efficient distribution of supplies of seeds as they became available. Vegetable seeds were rationed, and among its first actions the committee took steps to ensure that the different kinds were sent to those areas best suited to their growth, and that the armed forces were given priority for the resulting crops of vegetables.

As there were practically no reserve stocks of the kinds of seed regarded as essential, it was obvious that most of the vegetable seeds would have to be grown in Australia, and as quickly as possible. Efficient and quick harvesting of seed was surrounded by many difficulties, due mainly to the shortage of suitable machinery. This was alleviated to a large extent by machines imported from the United States under the Lend-Lease agreement, as the result of a mission consisting of an American officer Major T. Pozzy and the Australian agricultural expert Mr Douglass.[8]

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[5] Some growers produced special lines for a limited local clientele.

[6] J. R. A. McMillan, DScAgr. Principal Geneticist, CSIR, 1929-46; Professor of Agriculture, Univ of Sydney, since 1947. B. West Wyalong, NSW, 24 Feb 1901.

[7] The first chairman was Dr B. T. Dickson, CSIR Division of Plant Industry. The committee consisted of representatives of Commonwealth and State governments, of seed merchants and seed growers. McMillan was Executive Officer. In 1943 when Commonwealth Food Control was instituted the committee was reconstituted and Hon F. W. Bulcock appointed chairman.

[8] J. Douglass. Instructor, NSW Dept of Agriculture, 1937; Director of Agricultural Production, Dept of Supply, 1940; Chief Executive Officer Vegetable Production, Aust Directorate of Agriculture, 1942. Of Sydney; b. Wickham, NSW, 24 Apr 1900.

After much effort the Vegetable Seeds Committee succeeded in arranging for farmers to produce all the seed required for increased wartime food production, except carrot. Efforts were directed to growing varieties of seeds which produced crops well adapted for mechanised farming: peas that matured more or less simultaneously, so that instead of hand picking them several times, the whole plant was harvested; tomatoes that yielded fruit on parts of the plant accessible for repeated hand picking and not hidden under foliage; plants that grew tidily and allowed mechanical insecticide dusters and mechanical weeders to travel over them between their rows. Ordinary garden seed did not as a rule produce plants suitable for mechanised farming. Canning, to be successful, also required the use of special varieties of fruit and vegetable: cauliflowers that would keep their colour and shape, peas that softened well, tomatoes of high vitamin C content that retained their colour, and beans that were stringless. All these and more were produced.

The quantities of seed required were not large; for example, the estimated requirements for beetroot and carrots in 1942 were about 100,000 pounds of each. The committee had little authentic data upon which to base estimates of yields per acre in this country, but it anticipated that it would take about 300 acres to produce these amounts—a forecast which proved to be reasonably accurate. In some instances seed was overproduced, owing partly to the difficulty of estimating the needs of the fighting services. It was easy enough to estimate the needs of the civil population two years ahead, but it was another matter to do the same for all the forces in the South-West Pacific Area. In any event, reserves of 50 to 100 per cent—depending on the vegetable—were held in case of crop failures in succeeding years. The committee's handling each year of vegetable seeds worth about £1,000,000, with very little financial loss, was a most successful venture. Moreover its experience provided unquestioned evidence that Australia could become self-supporting as far as vegetable seeds were concerned.

The outcome of the drive to produce more vegetables may be seen from a few statistics. Between 1941 and 1945 the area devoted to growing potatoes was increased from 99,000 to 242,000 acres, with accompanying yields of 330,000 and 881,000 tons respectively. The area devoted to growing other vegetables nearly doubled over the war years:

1938-39	. .	125,000 acres
1943-44	. .	192,000 „
1944-45	. .	233,000 „

A large part of the supply of vegetables for the Services was drawn from Leeton and Griffith in the Murrumbidgee Irrigation Area; from Bathurst, Cowra and Windsor in New South Wales; the Goulburn Valley in Victoria; and the north-west coast of Tasmania. Great care had to be taken in selecting growing areas, which had as a rule to be reasonably close to canneries. When American authorities first asked for increased planting of green peas for canning, crops were sown so that they all matured simultaneously, with

the result that it was impossible for the neighbouring cannery to handle the entire harvest and much of it had to be ploughed in. Next year, on the advice of their experts, peas were planted at different times and in areas at different altitudes so that they matured at successive periods. Edgell's at Bathurst, for example, learned to extend their operating season considerably in this way. This is a simple illustration of the methods that had to be acquired in developing the vegetable-canning industry.

After Japan overran the rice-producing countries to the north of Australia a great expansion took place in the acreage devoted to growing rice in the Murrumbidgee Irrigation Area, where in the peak season (1943-44) some 4,000,000 bushels of paddy (unmilled or rough rice) were grown.

Increases in vegetable production were obtained to some extent at the expense of other agricultural industries. The decline of the dairying industry, which from 1942 onwards caused great concern, was undoubtedly the legacy of the failure to conserve rural manpower in the early years of the war.

In the pre-war period Australia depended almost entirely on outside sources of supply for the three main artificial fertilisers: phosphorus (in the form of superphosphate), nitrogen (as ammonium sulphate, and sodium nitrate), and potassium (as chloride and sulphate). Of these superphosphate was consumed in the largest amounts—at the rate of roughly 700,000 tons a year. This amount of superphosphate necessitated the importation of some 800,000 tons of rock phosphate from Nauru and Ocean Islands, where mining of the rock was managed by the British Phosphate Commissioners.

Aware of the vulnerability of Australian agriculture in respect of fertilisers, Dr Richardson of the C.S.I.R. wrote early in 1939 to the Federal Treasury asking whether Australia held sufficient stocks of rock phosphate to meet the emergency that would be created if supplies were cut off completely. He pointed out that from experimental evidence there was reason to fear a decline of between 20 and 30 per cent in wheat yields if supplies of superphosphate should fail. Under existing commercial practice about three months' supply was normally held by manufacturers. A plan was evolved, with the help of the British Phosphate Commissioners, to increase the reserve stocks of the rock phosphate from Nauru and Ocean Islands to six months' supply, and this was achieved by the end of June 1940. By the middle of 1941, owing to shortage of shipping and dislocation of operations caused by enemy attack on the islands, only 90,000 tons remained in reserve and supplies were coming forward so irregularly that the introduction of rationing was inevitable. When "scorched earth" plans had been carried out on 11th December 1941 after attacks by Japanese aircraft on Nauru and Ocean Islands, an intensive investigation was begun of low-grade phosphate deposits in Australia. Throughout 1942 and the early months of 1943 extensive trials were made on materials obtained from Molong and Canowindra (New South Wales), the Abrolhos Islands

(Western Australia), and Hermitage, St Johns and Orroroo (South Australia). The only deposit of any promise was that at Orroroo, but even this, which contained only 50 per cent of tricalcium phosphate (as compared with 87 per cent for rock phosphate from Ocean Island) gave disappointing results in manufacturing tests and confirmed the view of the Mineral Resources Survey that Australian phosphate deposits were too variable in composition and too low in grade to be worth working.

By the end of 1943 there was so much anxiety over the slow arrival of limited supplies from Egypt, Makatea and Florida that the Director-General of Agriculture asked the Prime Minister to cable personally to Mr Churchill so that submissions by Australian representatives to the United Kingdom Government asking for increased allocations of phosphates might receive support at the highest level.

Consumption of superphosphate in Australia had been reduced from the normal pre-war figure of about 700,000 tons a year to 480,000 tons, and in January 1944 the British Cabinet, convinced of the seriousness of Australia's plight, approved the immediate release of about 75,000 tons of shipping to load rock phosphate from North Africa. The gradual recovery of imports of rock phosphate from the lean years of 1942-43 can be seen from the accompanying table showing the production and consumption of fertilisers in Australia during the war. Increased imports of rock phosphate did not immediately end the country's fertiliser problems, for it was soon discovered that there was not enough manpower to operate the superphosphate industry at its full capacity. Only after the Director-General of Manpower intervened granting a temporary absolute priority in the allocation of labour to the fertiliser industry was the position gradually remedied.

Supplies of potash were proportionately meagre but were eked out by small amounts produced from deposits of alunite in Western Australia, and as a by-product from cement kilns in Victoria. Extensive use of ammonia and sodium nitrate in the explosives industry meant that agriculture was chronically short of nitrogenous fertilisers.[9] The increase in local production of ammonium sulphate was never able to overtake the loss of imports. Most of the ammonium sulphate used in agriculture was consumed by the sugar industry, but towards the end of the war the shortage was to some extent relieved by substituting sodium nitrate, of which the Munitions Department held more than it needed. This was not altogether a satisfactory substitute, for two reasons: it contained a smaller percentage of nitrogen than did ammonium sulphate, and was by reason of its greater solubility more readily leached out of the soil by heavy tropical rains. By the end of the war when the synthetic ammonia plants were brought into production the position was improved, though these plants were not large enough to make Australia completely independent of outside supplies of nitrogenous fertilisers.

[9] Agricultural chemicals such as nicotine sulphate (insecticide) and strychnine for rabbits (myxomatosis had not then been introduced) were in short supply.

SOURCES OF PHOSPHATE ROCK, 1938-46[1]
(in tons)

Year	Nauru-Ocean Is.	Makatoa	Christmas Is.	Egypt	North Africa	Florida	Total
1938-39	803,990						803,990
1939-40	701,361						701,361
1940-41	336,746		33,105	31,831			401,682
1941-42	86,742	39,986	61,119	98,672			286,519
1942-43		52,583		171,542			224,125
1943-44		62,234		185,215	31,702	50,871	330,022
1944-45		35,578		176,802	233,648	18,098	464,126
1945-46		50,079		161,243	374,439	68,393	654,154

PRODUCTION AND CONSUMPTION OF FERTILISER IN AUSTRALIA
(in metric tons)

	Nitrogenous as N			Superphosphate as P_2O_5		Potash as K_2O*		
Year	Production	Imports	Consumption	Production	Consumption	Production	Imports	Consumption
1939-40	5,400	4,200	9,600	226,000	226,000	—	7,500	7,500
1940-41	6,100	2,900	9,000	217,500	217,500	—	3,000	3,000
1941-42	5,900	300	6,200	152,300	152,300	—	1,600	1,600
1942-43	5,000	100	5,100	87,000	87,000	—	1,200	1,200
1943-44	4,900	3,400	8,300	95,700	95,700	300	2,000	2,300
1944-45	4,400	3,900	8,300	147,400	147,000	600	2,700	3,300
1945-46	4,500	8,600	13,100	208,300	208,300	700	5,400	6,100

Most of the imported potash came from Palestine, except in the early part of the war, when supplies came from France.

For many years a large industry based on the manufacture of agricultural machinery had flourished in various parts of Australia; over the years it had pioneered several revolutionary types of machine for harvesting cereals, and in 1939 it occupied a strong position in the country's secondary industry. During 1939-41 makers of agricultural machinery turned their energies to making munitions.[2] However when the production of food became all important and agricultural machinery was declared a munition of war, manufacturers returned to their normal activities. Many machines such as tractors and bulldozers were imported from the United States, but under the provisions of Lend-Lease Australia was required to provide whatever machinery she was capable of making. The Machinery Section of Commonwealth Food Control did everything possible to encourage firms to make new types of implement. On the technical side they were given

[1] Figures supplied by British Phosphate Commissioners.
Multiply by 1.7 for high-grade rock, 1.6 for other grades, to calculate approximate tonnage of superphosphate.

[2] H. V. McKay, Massey Harris, Pty Ltd, Sunshine, Vic; International Harvester Co of Aust Pty Ltd, Geelong and Dandenong, Vic; Howard Auto Cultivators Ltd, Sydney; Toowoomba Foundry Pty Ltd, Q'land; Horwood Bagshaw Ltd, Adelaide, SA; David Shearer Ltd, Adelaide; John Shearer and Sons Ltd, Adelaide.

valuable assistance by the Directorate of Ordnance Production and by a team of American experts led by Major B. L. Seabrook. More than 100 different types of machine were manufactured, 25 of them for the first time in Australia: power-operated potato diggers, rotary weeders, bean harvesters and a great many others. Old types of machine were adapted for new purposes: the Sunshine header for harvesting rice and navy beans and for harvesting and thrashing large quantities of vegetable seeds. The agricultural machinery industry succeeded in supplying local demands and also in sending many thousands of drills and cultivators, disc harrows and binders to Britain.

Despite the great increase in the local manufacture of some types of machine and the importation of large numbers of others from the United States, there were frequently not enough machines to go round. In order to meet this difficulty Commonwealth Food Control, towards the end of 1943, arranged for the formation of local pools from which agricultural machinery could be hired out to vegetable growers and others. The State Departments of Agriculture acted for the Commonwealth in the management and operation of the scheme, which covered all kinds of machinery used in the preparation of the soil, sowing of the crops after cultivation, and harvesting of vegetable crops: tractors and trailers, ploughs, delvers and levellers, grain and fertiliser drills, vegetable planters, transplanters, rotary hoes, crop dusters and power sprayers, crop harvesters such as bean cutters, headers and beet and carrot lifters; and tractor mowers and swinging windrowers.

Mechanisation was not new to Australian agriculture; what was new was its extensive application to vegetable production. Major Seabrook's unusually wide experience, gained on the largest farm of its kind in the United States (the Seabrook Farm Company, New Jersey), was invaluable in bringing about this minor agricultural revolution.

Since control of manpower, machinery, materials and production on a national scale could not well have been administered from a single centre, a large degree of decentralisation was adopted. An excellent example of what could be achieved in the way of decentralisation of direction had been provided by the County War Agricultural Committees of Britain. Inspired to a large extent by the example of these and of similar bodies in the United States, the Federal Cabinet, in September 1942, made a grant of £50,000 to finance the organisation of 146 District War Agricultural Committees throughout the Commonwealth. Each consisted of members serving in an honorary capacity and was under the chairmanship of a field officer of the State Department of Agriculture.

In the first instance the committees were set up for the purpose of giving farmers an opportunity of playing a substantial part in the direction and control of manpower in rural industry. No direct powers were delegated to the committees. They depended for their success entirely upon the voluntary cooperation of farmers. As their success became apparent the Government made a further grant of £100,000 in 1943-44 to enable their

activities to be greatly extended. Decentralisation was carried one step further by setting up some 2,000 local committees whose function it was to see that the available manpower was efficiently used, to exercise jurisdiction over machinery pools, to report on applications for fertilisers and other materials in short supply, and finally to stimulate local production to achieve the quotas allotted by Commonwealth Food Control. There is no doubt that the work of these committees, representing as it did the voluntary efforts of leading farmers—men who found time to help rural programs of activity in spite of the heavy calls on their time—was a valuable contribution to the success of the increased wartime production of food.

FOOD TECHNOLOGY

Since much of Australia's increased food output was destined for troops in the islands of the South-West Pacific Area, it was clear that increased facilities for preserving, transporting, and storing food would be essential. Wherever it was possible in Northern Australia, servicemen were fed with food grown on the spot; extensive vegetable farms were established by the army on the Atherton Tableland and in the Northern Territory, but this was not possible to anything like the same extent in New Guinea and other tropical islands.[3]

Problems of transport, storage and preservation of food were by no means new to Australia. Owing to her great distance from oversea markets (especially from Britain) and also to the long distances frequently involved in distributing foodstuffs within the Commonwealth, transport and preservation of food had for many years provided problems for the Australian economy.[4] Recognition of this had caused the Council for Scientific and Industrial Research to set up a section on Food Preservation and Transport, in the buildings of the Queensland Meat Industry Board at Cannon Hill, Brisbane, in 1931.[5] The Victorian Department of Agriculture also provided accommodation in Melbourne for investigations into the storage of fruit to be carried out jointly with its staff.

As Australia emerged from the economic depression the council was able to extend its plans for investigating a much wider range of problems relating to the transport and storage of food. By 1938 it had installed laboratories in buildings allotted at the Abattoirs at Homebush, New South Wales, where chemical, physical, and microbiological studies were carried out on the storage and transport of meat, fish, eggs and fruit.

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[3] In the Northern Territory, army farms during the dry season were very efficient and quite important, producing mainly tomatoes, cabbages, beans and melons. They contributed substantially to the fresh vegetable supply. No vegetables were sent from Queensland to the Northern Territory: they were sent overland from Adelaide via Alice Springs. The stimulus given by army farms had a lasting effect on the Territory.

[4] The first successful cargo of refrigerated meat to be sent on a long journey was one from Sydney to London in 1879-80, and was the result of work by T. S. Mort.

[5] The section was under Dr J. R. Vickery, who had gained experience from four years at the Low Temperature Research Station, Cambridge, and at the laboratory of Prof T. P. Hilditch at Liverpool. The cost of the laboratory for meat investigations was at first borne by the Q'land Meat Industry. When the section became a division Vickery became its chief.

Early in 1940 the Section of Food Preservation and Transport was raised to the status of a division. Its laboratories at Homebush were in fact the only centre in Australia where research in food science and food technology (with the exception of problems relating to dairy products) was being carried out and where there was a group of people who could advise on problems relating to the preservation of food.

After the outbreak of war the division dropped all investigations that did not have a direct bearing on defence and concentrated on problems concerning the supply of food to the armed services and to the United Kingdom.[6] Since much of the food supplied to the forces in forward areas would have to be canned or dehydrated, new sections of the laboratory were set up to deal with these processes.

On 10th November 1942 an incident occurred which caused alarm among food manufacturers and shook the confidence of the army authorities. At Portland Roads, Queensland, twenty-six American servicemen became suddenly ill from a form of food poisoning and within ten days seven of the men were dead. About three weeks later a similar incident occurred at Adelaide River, Northern Territory, in which six servicemen were suddenly taken ill with what again appeared to be a severe form of food poisoning. This time one man died—within three days. The only item eaten on both occasions was canned beetroot, and in each instance the cans were "blown" and the contents had a peculiar odour, colour and flavour. It seems surprising that the food was not rejected at once. Dr Gray[7] of the School of Bacteriology in the University of Melbourne, who investigated the poisonings in some detail, reported that:

> The available evidence is largely circumstantial because the toxic foodstuff was not recovered in either instance, but the epidemiological, clinical and post mortem findings, coupled with subsequent laboratory investigations, appear sufficiently convincing to justify the conclusion that the disease was in fact botulism.[8]

Although this was the first instance recorded in Australia of a disease which in the form of rare and isolated outbreaks had occurred in most countries where food was preserved, it suggested that process control in some vegetable canneries was not all it should have been, and it appeared to justify the misgivings of the American army experts referred to earlier.[9] The incident had important consequences.

American authorities had for some time been urging the Controller of Service Foodstuffs to set up within the Department of Supply a food tech-

[6] Vickery's work at Brisbane had led to the introduction of the valuable export of chilled beef, which was superior to frozen beef. Owing to shortage of refrigerated shipping space this export ceased early in the war.

[7] D. F. Gray, DSc, DVSc. Lecturer in Bacteriology, Univ of Qld, 1940-45; Senior Lecturer in Bacteriology, Univ of Melb, 1945-50, Assoc Prof since 1950. B. Sydney, 9 Jul 1912.

[8] D. F. Gray, "Human Botulism in Australia", *Medical Journal of Australia*, Vol. 2 (1948), p. 36.

[9] The Division of Food Preservation undertook an intensive study of conditions governing the proliferation of *Clostridium botulinum* and the development of its toxin. Despite investigations of this organism in many laboratories throughout the world during the previous 30 years, there were many things about it that were not fully understood. At Homebush it was found that tin dissolved from unlacquered cans tended to kill off the micro-organisms more effectively if the protein content of the vegetable being canned was low. This work had no practical bearing but it did explain a number of observations which had puzzled food technologists for some years.

nology section capable of safeguarding the quality of defence foodstuffs. Squadron Leader Mendelsohn,[1] who before the war had been a public analyst and keenly interested in food quality and standards of safety, and who was now temporarily seconded from the R.A.A.F. to act as adviser to Mr Davis,[2] was asked to bring together a staff of food technologists. The outbreak of botulism gave a sense of urgency to his mission and greatly accelerated the formation of a new technical section. On Mendelsohn's return to the air force the Research and Technology Section (as it came to be called) was placed in charge of Dr Kerr,[3] who had been released for the purpose from his post as Director of the Sugar Experiment Stations in Queensland.

One of the section's first objectives was to station university graduates in science or agriculture in canning factories not already possessing technically trained men—no easy task at this late stage of the war since most graduates in science were already engaged on other phases of war work. A second objective was to set up food testing laboratories in each capital city with staffs capable of examining daily the thousands of production samples of canned foods intended for the fighting services. Until then the Customs Laboratories had been able to deal with the occasional samples sent in by inspectors from the Department of Commerce, but the extensive nature of the tests now to be undertaken—involving bacteriological as well as chemical examination—overtaxed the laboratories in Melbourne, Sydney and Adelaide. The authorities were therefore obliged to provide additional laboratories. For a while testing in Melbourne was carried out at Parkville with the cooperation of the Commonwealth Serum Laboratories.

Fortunately, about this time the research laboratories of the Melbourne Metropolitan Board of Works were nearing completion. Portion of these had been set aside for the Navy Victualling Branch and after some negotiation by the Controller of Service Foodstuffs a section was granted for use as a Food Technology Laboratory. In Sydney the position was more difficult; space was first of all acquired at the laboratory of the Producers' Cooperative Distributing Society at Ultimo. The staff was later transferred to the Munitions Laboratory at Villawood and finally to a laboratory set up by Food Control in Sydney. In Brisbane food testing was carried out at the State Health Laboratory under the supervision of Mr Watkins,[4] Queensland Government Analyst. The Customs Laboratory at Perth under Mr Macleod[5] was able to conduct all quality control work for Western Australia. The position in Adelaide was not satisfactory until a laboratory was made available at the Salisbury Explosives Factory.

[1] Sqn Ldr O. A. Mendelsohn, BSc. Chemical adviser to RAAF 1942-45. Public analyst and musician. Of Victoria; b. Nanango, Qld, 12 Jul 1896.

[2] G. A. Davis. Controller of Service Foodstuffs 1942-43; C'wealth Director of Clothing and Textiles 1943-44; Gen Manager, C'wealth Disposals Commission, 1944-47; Gen Manager, Overseas Corporation, 1947-53, Managing Director since 1953. B. Bathurst, NSW, 26 Jul 1900.

[3] H. W. Kerr, PhD. Director, Qld Sugar Experiment Stations, 1932-43; Chief Food Technologist Dept of Commerce 1943-47; Director of Sugar Research Institute, Mackay, Qld, since 1949. B. Sydney, 18 May 1901.

[4] S. B. Watkins, MSc. Govt Analyst and Chief Inspector of Explosives, Qld.

[5] L. N. Macleod, BSc. Chief Analyst, Customs Laboratory, Perth 1939-45; Executive Officer WA (Technical) for C'wealth Food Control; C'wealth Analyst since 1949. Of Perth; b. Perth, 5 May 1907.

There were not enough properly trained men to staff all food factories, but a fairly satisfactory arrangement was made whereby the Department of Commerce inspector in each factory, after having been given some additional training in the principles of food processing, worked in close collaboration with food technologists supervising small groups of factories.

In the meantime American Army authorities had taken stock of the general position in Australia and readily agreed to requests that they should send out teams of food technologists and other experts, since such a course would be preferable to shipping food across the Pacific or to continually rejecting food that did not meet with their specifications.[6]

An American Army subsistence unit under Colonel (later Brigadier-General) H. B. Hester, was at first attached to the Department of Supply, but in February 1943 when General MacArthur informed the Prime Minister of Australia that the American food officers wished to procure their supplies through the Australian food authorities instead of through the Australian Military Forces, a separate subsistence depot with headquarters in Sydney and branch depots in Melbourne and Brisbane was established.[7] Serving under Hester, who became Commanding Officer of the Subsistence Depot, was a group of food and agricultural specialists who were to be of great help to Australian industry; it included Major B. L. Seabrook whose work on mechanisation in vegetable farming has already been referred to, and Major M. A. Joslyn, who before enlistment was Professor of Food Technology at the University of California. These experts set up the U.S. Quartermaster's Laboratory in Tooth's Brewery, Sydney, which was then placed in charge of Major C. R. Fellers, head of the Department of Food Technology of the University of Massachusetts at Amherst.[8]

In order to ensure that food supplied to the armed forces reached clearly-defined standards, Service authorities with the cooperation of the C.S.I.R. and the Technology Section of Commonwealth Food Control drew up specifications covering the necessary items of food. Sometimes the standards set by this Specifications Committee,[9] which were based on those generally accepted in the United States by the Agricultural Marketing Service, were beyond the capacity of the industry to meet, and it was occasionally necessary to relax them in the light of what could in the circumstances be reasonably expected of the industries concerned. For instance the industry had no brine separators for washing and taking out the very old and very young peas; it had no pea harvesters, though before the war ended it began cutting the vines instead of picking the peas;

[6] Mr J. Douglass, Director of Agricultural Production in the Dept of Supply, was one of the most active supporters of these proposals.

[7] K. R. Cramp, "Food the First Munition of War—American-Australian Cooperation", *Journal and Proceedings of the Royal Australian Historical Society*, Vol. 31 (1945), p. 65.

[8] Others in this team were: Major T. Pozzy, Major M. D. Miller, Major G. Hallman, Col C. Cowherd, Lt-Col F. W. Crawford, and Capt C. E. Norton.

[9] This committee continued to function long after the war, revising and bringing its work up to date, and a detailed set of specifications bound together in a substantial volume entitled *Commonwealth Food Specifications* was issued by the Department of Commerce as a guide to food manufacture. These specifications were based on sound technological principles and were adopted by the procurement sections of the armed services.

it had no stringless bean seed but had a makeshift method of stringing the ordinary garden beans. Once standards had been laid down the next step was to devise methods for ascertaining whether they had been achieved. A special committee of the Royal Australian Chemical Institute promulgated standard methods for the chemical analysis and examination of foodstuffs.

In the canning of food the main objective was to destroy micro-organisms that would cause spoilage, and at the same time to retain the nutrient qualities and palatability of the food. Thus all canned food was cooked, and as might be expected the degree of sterilisation obtained depended to a large extent on the time and temperature of the cooking. Specifications, based on those used by the National Canners' Association of America, which had made an exhaustive study over many years of the problems of safe processing, related mainly to these two factors. Australian manufacturers were of course aware of the importance of these factors. Fruit had been successfully canned in Australia for many years and a valuable export trade had been built up, but before the war relatively few firms had attempted to can vegetables.

Canning of vegetables demanded more care than canning of fruit. Most vegetables, not being acid in reaction, were favourable media for the growth of heat-resistant spore-forming bacteria, some of which were dangerous. If serious spoilage and the risk of fatal food poisoning was to be avoided it was necessary to ensure that the vegetables were heated to a sufficiently high temperature (above the boiling point of water) for a sufficiently long time during the canning process. Temperatures and times had, however, to be precisely specified since overcooking tended to destroy the flavour and other desirable qualities of the product. Great care had also to be exercised to avoid even a minute leak in the seams of the cans through which bacteria might enter after processing. The strictest control of factory operations was therefore essential. The few firms that had attempted to can vegetables before the war had done it successfully, but when vegetable canning was first begun on a large scale, as it was in 1944, many of the newer firms lacked the technical means for securing proper control of temperature during the cooking process—or else did not make effective use of them. They also lacked the scientific staff to supervise and control processing operations. However, once the specifications had been widely promulgated and put into effect and a system of thorough inspection had been instituted, no difficulties were experienced in achieving efficient processing. Attention was thereafter directed to producing canned foods of the highest possible quality.

The quality of canned vegetables, of whatever kind, was determined principally by the quality of the raw materials. Recognition of this basic fact led to the expansion of agricultural field services designed to advise growers on the culture of crops and selection of varieties. Rapid handling of crops from field to cannery was essential: to preserve nutritive properties the entire process had to be completed within a few hours. It was the

custom for experts to advise the farmer on the varieties of vegetable most suitable for canning, when and how to grow them, and when to harvest. For example, from the topographical position of a field of peas, from the weather and from tests of the starch content, an expert could predict approximately when the crop would be ready for canning or freezing. All this was essential for efficient processing. However, certain varieties of vegetables found satisfactory for canning when grown in the United States, occasionally proved to be dismal failures when grown in Australia and canned in exactly the same manner, which meant that studies had to be made of locally grown varieties to decide those most suitable for canning. This was done by the C.S.I.R. in collaboration with State departments of agriculture, horticultural research stations and progressive individual growers.

Considerable attention was paid by the Division of Food Preservation to the processing of cured meats. In canning bacon rashers, for example. the problem was to give the bacon a heat treatment sufficient to prevent spoilage by micro-organisms yet not so severe as to destroy the texture and form of the rashers. The problem was solved by compromising between the two, with results that were not always satisfactory.

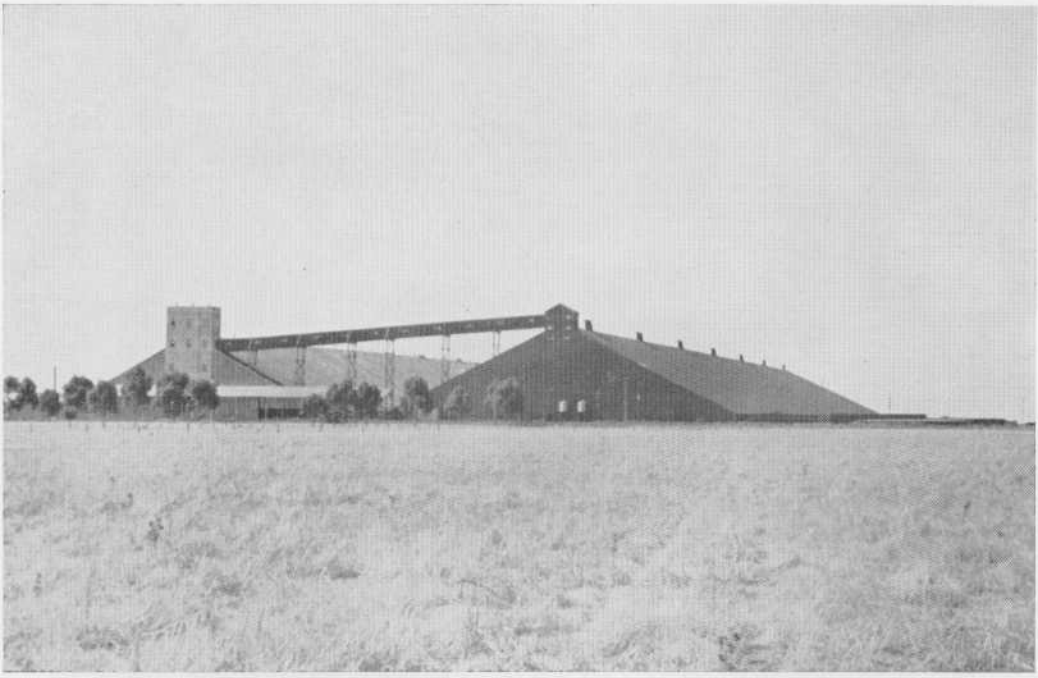
The canning industry itself made a great effort. At the beginning of the war it was not fully mechanised either in the field or in the factory. The need for mechanisation was not so pressing then; rural labour was plentiful and cheap. All this was changed after Japan entered the war, when the grave shortage of manpower made mechanisation a major objective. It was in this respect that the "American invasion", consisting as it did of skilled management and technicians, made its deepest impression on the industry. Without their drive the canning industry might have taken years to accomplish what it did in months. Another determining factor was the Government's provision of money for machines and equipment, which suddenly became available through Lend-Lease, and without which American methods could not have been implemented. The Australian industry, wholeheartedly cooperative and willing to learn, strained every nerve and all its resources to increase the volume and variety of its output and to improve standards of quality. The accompanying table[1] will give some idea of the increase in the production of canned vegetables alone over the war years.

	1939	1943	1944	1945	1946
Beans . .	55,400*	233,500	136,400	280,000	
Beetroot .	47,100		184,000	386,000	
Carrots .			304,500	926,000	426,000
Peas . .	44,300	85,500	222,000	400,000	
Tomatoes .	37,600	216,500	170,000	177,000	

* Cases of 24 2½-inch cans.

The insistence on high standards of food for the armed services did much to raise the general level of food technology in Australia. Under the

[1] Taken from C. E. Norton, "Technological and Economic Advances in the Australian Canning Industry since 1938", *Second International Congress on Canned Foods* (1951), pp. ix-l.



(Grain Elevators Board)

Front view of two emergency wartime storages at Murtoa, Victoria. The storage on the left has a capacity of 3,500,000 bushels and is constructed of timber and galvanised iron with a concrete floor. That on the right is of timber and black iron with a galvanised iron floor, and has a capacity of 7,500,000 bushels of wheat.

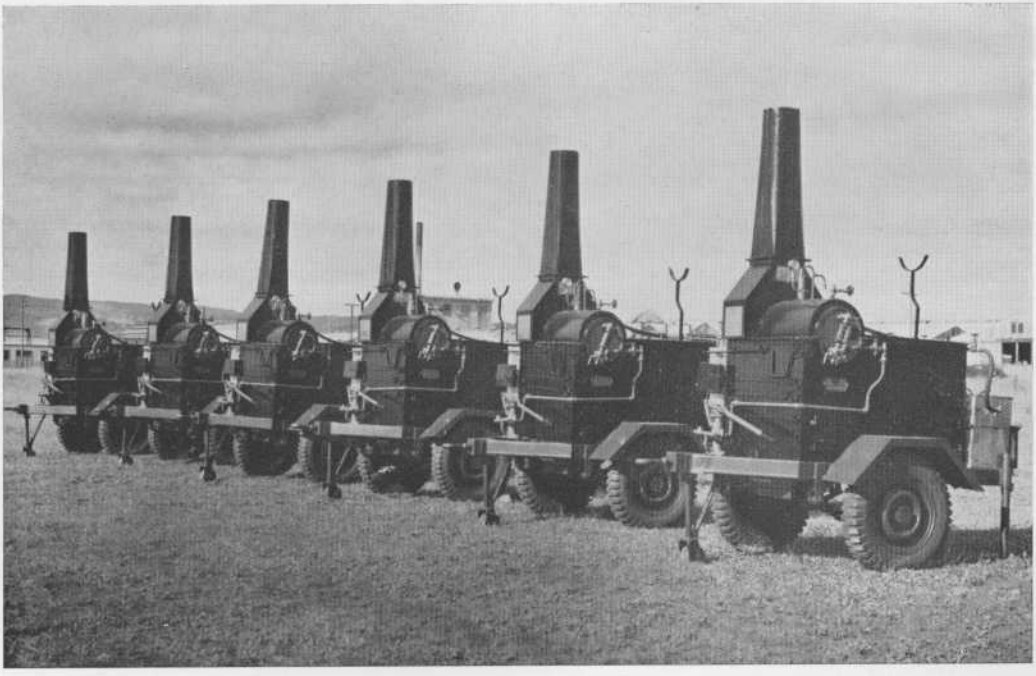


(Cooperative Bulk Handling Ltd)

Wheat silo at Fremantle.



Green crop loader at Bathurst, New South Wales. *(Edgell's)*



Wiles Junior mobile steam cookers awaiting shipment to New Zealand.

stimulus of war "Australia's canning industry . . . passed through a stage of technical and economic development . . . surpassed by few other countries during this period".

One of the problems of feeding troops in tropical (and desert) areas was to ensure that they got enough vitamin C, which normally came from the fresh fruit and vegetables in the diet. Vegetables noted for their high vitamin C content often lost a great deal of it during the process of canning, despite all measures taken to prevent this loss. Hence a good deal of effort was put into searching for methods by which fruit juices could be preserved without destroying their vitamin C content. The Division of Food Preservation had these investigations well in hand by the time the Services began to ask for canned fruit juices, and quickly passed their results on to industry.

Special attention was paid to citrus and apple juice, while pineapple, black currant and grape juice and rose-hip syrup were not overlooked. Processing details worked out by the division were applied in the large number of fruit-juice plants set up, mainly by cordial-makers, at the request of the Department of Commerce and Agriculture. Few technical difficulties were encountered in canning the juices except those of citrus fruits. Apple juice by itself did not contain much vitamin C, but being highly palatable and greatly in demand in the tropics, it was fortified with synthetic vitamin C.[2]

Confirming earlier American experience, food technologists in Australia found that juice from navel oranges, which made up about 50 per cent of the Australian citrus crop, was unsuitable for canning because it contained a bitter principle (limonin). Valencia oranges were more suitable though they also occasionally developed a bitter flavour from the same cause. When stored for long periods at ordinary temperatures valencia juice tended to develop "stale" flavours. In practice the juice was held at low temperatures for as long as possible before issue to the troops. Only after the war were really successful methods of preserving orange juice (vacuum concentration followed by freezing) devised.

During the early days of the Australian canning industry individual firms had made their own cans. The standards of can manufacture and sealing in Australia were adequate for fruit and jams, which were less sensitive to spoilage by micro-organisms entering through seam leaks, but when such cans were used for vegetables and meat and sent to the tropics serious troubles were experienced. At first some food was wasted because of defective cans. One of the main causes of spoilage in canned foods was the entry of micro-organisms through faulty end and side seams. Sealing had to be more nearly perfect with vegetables and meat because entering micro-organisms flourished so much more readily in these than in acid fruits.

[2] This was made by the Colonial Sugar Refining Co.

One of the first things the American food technologists did was to help industry improve the manufacture of cans, both in quality and speed. Automatic machines were imported under Lend-Lease, some to serve as models for local manufacturers. In a remarkably short time four Australian engineering firms manufactured much of the automatic can-making machinery required for the rapidly-expanding food industry, which in 1944 turned out about 1,250,000,000 cans, most of them for the armed forces.[3] Great credit is due to these firms for the response they made. American experts visited food factories to help technicians in making sure that can-closing machinery was operating satisfactorily. Prominent among the American technologists who helped to improve the standards of can making was Captain C. E. Norton.

There could have been no expansion of the canning industry had there not been adequate supplies of tinplate—sheet steel coated with tin. No substitute for it was found that was satisfactory for all occasions. Steel gave the plate strength, while the tin coating served the dual purpose of protecting the steel against corrosion and enabling perfect closure of a can by soldering. One of the few weaknesses of the Australian steel industry was that it did not manufacture tinplate; such an industry would have taken several years to build and develop. The Broken Hill Proprietary Company Ltd had planned, several times since its inception at Newcastle, to begin a tinplate works, but each time the attempt was abandoned because of adverse economic conditions. Not until 1939 did it seem likely that local industry would be able to make tinplate that could compete with the imported product. With the promise of tariff protection in the early stages if it should prove necessary, the B.H.P. made plans to begin the industry at Whyalla in 1939. The war put a stop to this scheme: the steel industry was far too heavily committed to making steel for munitions for there to be any hope of starting on such a big new venture. Australia was therefore compelled to depend on outside supplies for all her requirements of tinplate, which in peace time amounted to about 75,000 tons a year. Control of the importation and use of tinplate was in the hands of the Department of Supply, advised by the Commonwealth Tinplate Board. Its procurement in the United States under Lend-Lease was ably arranged by Mr F. Elsworth, whose efforts led to imports rising as high as 120,000 tons a year, but even with this increase it was only by careful control—using it only for essential foods that could not be packed satisfactorily in any other way, and by permitting the use of cans only above certain minimum sizes—that the requirements of the food industry were met.

For a while there was a great deal of anxiety about the supplies of tinplate, and a special committee known as the Substitute Containers Committee, comprising food technologists and industrial experts, was set up

[3] The firms were: John Heine and Sons and J. Jardyne Pty Ltd of Sydney, and W. G. Goetz and Smith & Searls of Melbourne. Two of these firms had been engaged before the war in manufacturing automatic can-making machinery capable of turning out 300 cans a minute.

to devise useful alternatives. They did not achieve very much because materials were so short that they were often confronted with the necessity of finding a substitute for a substitute. For instance, cardboard impregnated with paraffin was a promising substitute in some circumstances, but there was little paraffin wax. Wax was eked out with mixtures containing hydrogenated oleostearine, but containers made with it had a rather limited usefulness. Owing to the general scarcity of all materials that might have been useful, very little could be done in finding substitute containers for foods highly sensitive to external storage conditions or for less sensitive foods stored under unusually hot or moist conditions. For the less sensitive foods stored under normal conditions quite satisfactory substitute containers were devised. A unique achievement of this committee was the working out of a method of re-using tinplate containers, which resulted in some 20,000,000 being used at least twice.

Properly dehydrated vegetables retained a good deal of their original vitamin content and were in fact more nutritious than fresh vegetables in poor condition.[4] Early in 1941 the Division of Food Preservation, convinced of the great advantages to be had in the way of saving weight and space, began to study the technical problems of dehydrating eggs, meat and vegetables. Some idea of the possible economy in shipping may be gathered from the fact that 80,000 tons of vegetables decreased in weight to 10,000 tons on being dehydrated. A great saving in tinplate was another advantage offered by dehydration.

For the most part industry was not willing to erect dehydration plants, and despite constant urging by the C.S.I.R. and other technical bodies it was not until well into 1942 that the Department of Commerce accepted the responsibility of building these plants. It then became one of the biggest projects carried out by the Department of Commerce and by Commonwealth Food Control during the war, and resulted in the establishment of 32 dehydration plants, 24 of which were new installations; the remainder were converted fruit-drying plants. The setting up of a new plant involved the erection of a building (usually by the Allied Works Council), the installation of boilers and processing machinery, and the construction of the dehydrator itself, which was essentially a tunnel through which hot air could be circulated. Since the necessary processing machinery could not be imported it had to be made locally. Roughly 75 per cent of all the processing machinery for the dehydrating plants was made by Messrs W. D. Bingham Pty Ltd of Melbourne. The dehydrators were designed by Mr I. McC. Stewart and a team of assistants. The first dehydrators were fabricated steel structures, but by mid-1943 a two-stage brick tunnel had been evolved which became standard equipment. These tunnels needed only minor modifications when more technical information came in from

[4] Dehydration must be distinguished from drying of food. Both processes achieved the same end—removal of water—but differed in degree and in the means employed. Fruits, such as apricots and raisins, were dried slowly in the sun at ordinary temperatures. Dehydration was carried out much more rapidly by circulating hot air under carefully-controlled conditions of temperature and humidity, over food which passed slowly through long chambers or tunnels.

overseas. In the earlier installations the dehydrator was usually constructed as an annexe to an existing food-processing plant, but before long it was realised that it was desirable to take the dehydrator right to the growing area, and this became the general policy. They were thus distributed throughout the Commonwealth. Officers of Food Control supervised the installation of the plants, selected the staff, and stood by to give instructions until production was satisfactorily established. The plants were then taken over and managed on a cost-plus basis by firms experienced in the processing of foodstuffs. Investigations on the process of dehydration were undertaken by the Division of Food Preservation in collaboration with visiting American food technologists.

Some of the early problems that had to be solved were: to select the varieties of vegetables best suited for dehydration; to find the most suitable method for blanching these vegetables (a process consisting essentially of putting them through boiling water or steam to destroy the enzymes that hasten deterioration); to discover the optimum conditions for dehydration; and finally, to devise satisfactory methods of packing and storing dehydrated foods. After these problems had been solved the main concern of the laboratories was to study the factors influencing the deterioration of stored dehydrated foods. All foods, however well preserved, underwent slow deterioration. Some of the difficulties encountered with the deterioration of dehydrated foods in the tropics will be considered in a later section.

Production of dehydrated vegetables rose from 2,000,000 pounds in 1942 to 24,000,000 in 1944, from which it can be seen that the project developed into one of considerable magnitude. Vegetables were not the only foods to be successfully dehydrated: whole egg powder was supplied to the Services at the rate of several thousand tons a year.

Once the temperature was brought down low enough food could be kept almost indefinitely in the frozen state, but it was quite another matter to be sure that when it was thawed out the original colour and flavour would be retained. When frozen meat was thawed, for instance, it often presented a very unattractive appearance, caused by the escape of fluids—a phenomenon sometimes known as "drip". It was discovered that quick, or flash, freezing greatly diminished spoilage of food: quick-frozen beef did not exhibit "drip" on being thawed. Meats, poultry, fish, fruit and vegetables could be preserved in this way for long periods with little deterioration.[5]

Quick freezing was carried out in air tunnels through which well-cooled air was circulated. After cleaning, blanching, sorting and weighing, vegetables were loaded into trucks and then slowly moved through the tunnels, beginning at one end where the temperature was about 0 degrees Fahrenheit and emerging from the other where the temperature was about minus 20 degrees. The whole freezing process occupied about an hour. Thereafter the food was maintained at the lowest temperature, and of necessity could be transported only in properly equipped trains or ships. Quick-frozen

[5] The method was first used in Victoria by Seafresh Seafoods Pty Ltd.

food was not used by the Australian forces because it required too much equipment all along the line of supply, but it was used on a small scale for supplying American hospitals.

FEEDING THE ARMED FORCES

We come now to a final and essential stage in the flow of food supplies —their distribution and use by the armed forces.[6] The intricate problem of organising the transport and distribution of food to more than 750,000 men over a vast area—the Middle East, Singapore, the Commonwealth and the islands of the South-West Pacific—was successfully handled by Brigadier McDonald[7] and his staff.

While the drive for increased production of food was being launched, changes designed to improve the use of food were taking place in the army. After a long campaign beginning early in 1940, Stanton Hicks finally persuaded army authorities to set up an Australian Army Catering Corps as part of the organisation of the Branch of the Quartermaster-General.[8] This move brought Australia into line with other countries of the British Commonwealth. Stanton Hicks became first Chief Inspector of, and later Director of, Army Catering, a position he held till the end of the war. It was the business of the Army Catering Corps to bring the latest results of the study of human nutrition to the soldier's mess, to see that food was correctly used without waste and loss of savour (in itself a primary cause of waste), and to supply technical advice and technicians wherever they were required.

Education in the elementary principles of nutrition was extended to the soldier himself, since it was important to dispel a fairly common belief that the foods comprising his ration were the result of an arbitrary choice, or worse still that they were chosen because they were cheap. The nutritional significance of the ration was explained to him; he was instructed how to keep waste to a minimum, and was in general made aware of the significance of good diet to his personal welfare.

Convinced that the cook was the weakest link in the chain of army feeding, Stanton Hicks set about "up-grading" him. Previously the status of the army cook had been so low—quite undeservedly—that it was difficult to attract suitable men to the job; duty in the cookhouse was in fact often part of the lighter penal system of the army. Nevertheless, in the last analysis, proper use of the food delivered by the supply and transport services depended very much upon the cook. He was the key man at this point. Through the provision of incentives in the form of possible promotion to warrant officer, and by training cooks to a much higher technical level than had hitherto been possible, the Army Catering Corps, which by the end of the war numbered 17,000 officers and men, did much to improve efficiency in feeding troops.

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[6] Beyond a brief reference to rationing, no attempt will be made to discuss the distribution and use of food by civilians.

[7] Brig R. T. A. McDonald, OBE. (Served 1st AIF.) Dir of Supply and Transport, AHQ, 1940-45. Regular soldier; of Toorak, Vic; b. Warrnambool, Vic, 21 Nov 1885.

[8] By General Routine Order No. 209, 12 Mar 1943.

Poor and inefficient methods of cooking spoiled more food and caused more dissatisfaction among troops than almost any number of possible deficiencies in the supply services.

As a sergeant cook in the South African War, Mr J. F. Wiles of Adelaide had been deeply impressed by the primitive nature of the methods used in catering for soldiers, and had decided that something should be done about them. Some years after his return to Australia he designed and built a steam cooker which was used in Gallipoli and in Egypt during the first world war, though without official sanction. Its use was discontinued owing to a decision after the war that all equipment should be standardised with that of the British Army.

Wiles died before the second world war, and the Wiles Manufacturing Company passed to his four sons. Not long after war broke out the Wiles brothers redesigned the steam cooker so that it could be used for fast motor transport, and then tried to interest the army in it. After meeting with some indifference at first, their efforts came under the notice of Lieut-Colonel Blackburn,[9] who encouraged trials with the 18th Machine Gun Regiment at Gawler, and demonstrated that the unit could be adapted for use by mechanised armies. Mobile or stationary, the Wiles cooker, whose essential feature was the use of steam, injected under pressure of 50 to 100 pounds per square inch, and at temperatures ranging from 298 to 338 degrees Fahrenheit, as the heating medium, possessed many advantages which Stanton Hicks was quick to bring to the attention of army authorities. These advantages—conservation of fuel and of food (which could not be burned by this method of cooking), of flavour and nutrient factors (especially vitamin C), coupled with high speed of cooking, provided powerful arguments for the adoption of kitchens equipped with steam cookers.

One of the earliest demonstrations of the usefulness of the mobile Wiles steam cooker took place during the construction of the strategic road from Alice Springs to Birdum. The intensely hot climatic conditions under which this road was built made its completion a feat of some distinction. A notable factor contributing to its success was efficient feeding of the men. It has been stated on the authority of the construction engineers and medical officers that no large group of men working so continuously under such arduous conditions ever enjoyed so low a sickness rate. In achieving this success, the mobile steam cooker played no small part. Thereafter the army placed orders for large numbers of mobile units.[1]

Owing to the long delay that attended the introduction of the mobile steam kitchen, it was never used in the way originally intended—for troops on the move in forward areas. It was, however, used on trains, on ships, at beach-heads and in field hospitals. The manufacturers claimed that it was the first army kitchen in which cooks could prepare complete

[9] Brig A. S. Blackburn, VC, CMG, CBE; LLB. (Served 1st AIF.) CO 2/3 MG Bn 1940-42. Barrister. City Coroner, Adelaide, till 1947; C'wealth Conciliation Commssnr since 1947. B. Woodville, SA, 25 Nov 1892.

[1] Col Sir Stanton Hicks, "The Feeding of the Soldier: Lessons from the S.W. Pacific Campaign". The unit was a combination of oven and steam boiler, with food containers and steam stockpots.

meals for troops on the move. Altogether more than 2,500 mobile and stationary steam cookers were manufactured.[2] Large numbers of stationary units were used in military camps throughout Australia; 1,500 units of both kinds were purchased by the American Army, which rated them highly. The British Mission, under Major-General J. S. Lethbridge, which first saw and reported on the Wiles steam kitchen in New Guinea in 1943, was particularly impressed by its efficiency.

Operational rations were intended for use in exceptional circumstances —for example in forward areas in the jungle—and wherever normal supply and feeding were impossible. They were designed as a compact ration to contain all the nourishment necessary to sustain a hard-working man for a definite period. It was easier to say in general terms what an operational ration should be capable of than to design it and have it manufactured in an acceptable form. The aim was that it should contain all the accessory food factors such as vitamins, together with the right amounts and proportions of fats, proteins and carbohydrates to provide 4,400 calories a day; that the food should not deteriorate when stored under the most adverse conditions; that when packed, the flavour of one food should not spoil that of another. All this was to be achieved without sacrificing palatability.

The first call for a ration of this type came suddenly—to supply the hard-pressed forces on the Kokoda Trail. Manufacture of the various components of special field rations had been organised by then but nothing had been done about packing them. Many problems were involved in this since a moisture-proof container capable of withstanding the humid conditions of the tropics was essential. Nestle's Food Specialties (Australia) Ltd undertook to pack the ration. Within six days after the first order had been received, the rations packed in special waxed containers were being dropped to the men on the Kokoda Trail.

Later this pack (which came to be known as A.M.F. Operation Ration Type 02) was improved. Some of the individual components were better protected and the whole ration was sealed in tin containers, each holding separately-wrapped concentrated rations for three meals. The components of the ration were:

Meal 1

Meat:	1 x meat or meat-and-vegetable component, 4-oz can
Biscuits:	1 x 2½-oz cellophane packet, 9 carrot biscuits
Fruit and cereal:	1 x 3½-oz compressed block—wrapped in cellophane, composed of dried fruit, cereals and nuts. Contained vitamins A and B, and iron
Caramel:	1 small bar wrapped in cellophane paper
Sugar:	2 tablets
Tea:	1 cellophane packet (approx 2 teaspoons)
Peanut butter:	1 x 1½-oz tin
Salt:	2 tablets
Barley sugar:	4 tablets
Wooden spoon.	

[2] Letters Patent Australia 111,905 (1939), 115,657 (1941). Patents applied for Great Britain 16117 (1940), Canada 493479 (1943), United States 361,230 (1940).

Meal 2

Meat:	1 x 4-oz can meat or meat and vegetables
Biscuits:	1 x 2¼-oz cellophane packet 8 wholemeal biscuits
Wheat lunch:	1 x 3-oz compressed block containing condensed milk and glucose syrup
Lime confection:	1 packet Fruit Tablets fortified with vitamin C
Sugar:	2 tablets
Tea:	1 cellophane packet
Milk powder:	1 „ „
Cheese:	1 x approx 2-oz tin cheese
Barley sugar:	4 tablets
Salt:	2 tablets

Meal 3

Meat:	1 x 4-oz tin meat and beans
Biscuits:	1 x 2¼ oz cellophane pack, 8 wholemeal biscuits
Chocolate:	1 x 3-oz tablet, greaseproof wrapped, chocolate which did not soften at high temperatures
Caramel:	1 small bar, in cellophane wrap
Sugar:	2 tablets
Tea:	1 cellophane packet
Jam spread:	1 x 2-oz tin lemon butter or passionfruit spread
Barley sugar:	4 tablets
Salt:	2 tablets
Wooden spoon.	

Nestle's continued to pack different types of emergency rations in large quantities—some 3,500,000 in all. In the opinion of battalion and company commanders whose units had used it, Field Operation Ration Type 02 was invaluable for troops in forward areas and provided more than the minimum needs for one day.[3] Some commanders suggested that the ration should be supplemented with tobacco, but as there was already a good deal of pilfering of the ration the suggestion was rejected. The ration was sometimes subjected to misuse by the men, who extracted some components, such as the chocolate, for use on ordinary occasions.

Having done all that was possible to ensure adequate supplies of the highest quality food to men in forward areas, the authorities decided to send a small party of scientists from the Division of Food Preservation to report on how food was standing up to storage conditions in the tropics, how effectively the supplies were being used, and how far they were actually meeting the needs of the men.[4] The report of these experts, made after an extended period of observation at Lae, Madang and Aitape, and the record of many discussions between them and the officers of the catering corps and the men, may be taken as more impartial than

[3] Lt-Col A. G. Wilson, who made a tour as an observer in New Guinea, commented in December 1943: "The new field operation ration is thought of highly and liked by the troops. It appears to be too sweet, but one officer who had lived on it for four days stated that after the first day the sweetness was not noticed as with the heavy exertion the body demanded plenty of sugar."

[4] E. W. Hicks, J. F. Kefford and H. S. McKee, "Report on Food Stores in New Guinea". Scientific Liaison Bureau and Division of Food Preservation.

random comments from the men themselves. It would have been too much to expect that there would be no waste, no deterioration of food and no unpopular varieties of food, but it was important, if manpower and materials were not to be misapplied, to know fairly clearly the extent of waste and deterioration and just where, how and why it was occurring.

One of the chief difficulties encountered in feeding men in the tropics was that of overcoming monotony of diet. Fresh foods possessed an importance in this respect which was out of proportion to their purely nutritive value. Though considerable effort was needed to ensure that fresh food reached its destination in a satisfactory condition, it was amply rewarded by the effect on morale. The most successful among fresh meats was frozen, boneless beef, but in removing bones so that the meat could be most economically packed, the unusually high ratio of surface to volume of meat thus created provided greater opportunities for bacterial contamination, which made it a highly perishable food if it was not handled properly. After thawing, the meat was liable to undergo rapid deterioration, but until then it was perfectly safe. These failures in handling were fairly numerous, but waste from this source was not as extensive as that from frozen mutton, which, weight for weight, took up much more cargo space. Although the very limited refrigerated shipping space was sometimes allotted to food that could better have been carried as deck cargo, there is no doubt that the shortage of refrigerated trains and ships did much to increase the difficulty of supplying fresh foods in the tropics. Live beef shipped to hospitals at a time when practically no refrigerated space could be obtained, proved too costly in terms of manpower and shipping space to be considered as a normal practice.

Shipping space was not always wisely used for the supply of fresh vegetables, as for example when sweet potatoes and other vegetables that could easily have been grown on the spot were sent up from the south. Army farms, numbering eight in all, did much to assist in the supply of fresh vegetables, especially to hospitals. The visiting food technologists were impressed with the efficiency and keenness of the men running these farms, but not with the planning of production from the farms. Attempts to grow potatoes, for example, represented so much wasted effort, because tropical soils teemed with micro-organisms inimical to potatoes.

No method of preserving food could prevent a slow deterioration on prolonged storage. The palatability and the nutrient qualities of the product depended to a large extent on the method of storage used, and this was especially true in the tropics. Devising suitable methods of storage in forward areas presented army supply authorities with one of their most serious problems. Losses of shell eggs were extensive, amounting at times to as much as 10 per cent; the technical problems relating to transport and storage of eggs had by no means been overcome at this time. Similar losses occurred with bacon and hams, due in this instance to faulty curing and inadequate smoking, and to their being left too long in storage.

Of the three forms in which butter was used in New Guinea, the frozen form was most appreciated and cost much less to supply than tropical spread or concentrated butter. The use of frozen butter was, however, limited by the amount of refrigerated space available for its transport. The unpopularity of tropical spread, a butter substitute, was frequently due to the fact that it was served straight from the can; but even when it had been reconstituted with water, dried milk and salt it could readily be distinguished from butter in colour, flavour and texture. Owing to the shortage of cooking fats, tropical spread usually found its way to the frying pan. Canned, concentrated, hardened butter which appeared in forward areas in 1944, had a much better reception.

By and large the quality of canned foods was satisfactory at the time the scientific party arrived in New Guinea.[5] Nevertheless they were often unpopular—some varieties inherently so, under all circumstances, as was the case with cabbage, sauerkraut and some kinds of fish. A pack of herrings from Western Australia was described by the party as "revolting". The truth was that the species of Australian fish being canned at this time were inferior and unsuitable for the purpose. It must be added that Californian pilchards—known to the men as "goldfish"—were no more popular. The acceptability of even the more highly regarded types of canned food, such as fruit, was often seriously reduced by too-frequent issue. Occasional stupidity in issuing large supplies of one type of food resulted in units' having to endure such delicacies as canned peaches, asparagus or apple jelly for months. No food, however well preserved, could retain its popularity in these circumstances. There was some evidence that in ordering food full advantage was not always taken of the variety available.

Canned citrus juices, among the most important of the processed foods, contributing significant amounts of vitamin C to the diet, were almost universally popular and filled a real need for a palatable beverage in tropical areas. It was noticeable that in the tropics orange juice that had become distinctly bitter was acceptable; in cooler climates, however, the troops would not tolerate the bitter juices. Black currant syrup, which had a high vitamin C content, was not nearly so acceptable, mainly because of its excessive sweetness.

Apart from the decline in popularity suffered by all processed foods when one kind was served too frequently, dehydrated vegetables were generally eaten in the amounts provided; in other words, they were moderately acceptable though never popular. The chief difficulty in the way of their efficient use was that of distributing and consuming them quickly enough, since they deteriorated far more rapidly in the tropics than in cooler climates. On the whole they would have been more useful if they had been stored in cooler temperatures in the south and shipped to the

[5] Those failures that did occur were as a rule due to leaky cans and to corrosion caused by unsatisfactory storage. Huge stocks of canned food were often stored in the open or inadequately covered for months on end. The effect of alternating hot sun, rain and cool nights soon made "breathers" out of the cans and thus brought about damage to flavour and texture. The development of "off" flavours due to improper or too-lengthy storage did much to make canned vegetables unpopular.

tropics at the last possible moment. Deterioration of dried egg led to serious waste which could have been largely avoided had the mainland practice been followed of holding it in cold storage until a few weeks before it was to be used. In the light of the report of the scientific survey it must be concluded that the problems of storing and distributing canned and dehydrated food in the tropics were only partly solved.

Vitamins of the B group were known to be essential in maintaining appetite and morale under the enervating conditions of the tropics; they also played an important part in restoring sufferers from malaria to health. Of the readily available and generally consumed foods, bread and cereals were the most important sources of these vitamins, but only if they were treated in the proper manner—bread to be fortified, cereals such as wheat to be eaten whole. Bread made from whole meal, or from white flour fortified with wheat germ, added greatly to the vitamin B1 content of the ration and brought it well within the limits considered essential for a satisfactory diet.

To make the best use of the nutritive factors available in wheat, which could be much more easily stored in the tropics than flour, the Army Catering Corps undertook an intensive campaign advocating the eating of porridge made of wheat ground sufficiently fine to give it a nutty consistency. The corps had first to dispel the myth that porridge was "heating". Further, it was necessary to emphasise the need to cook the porridge carefully, to serve it firm and to eat it with a liberal supply of milk (from milk powder) and sugar. Stanton Hicks reported that when the reasons were fully explained, the men responded remarkably well to the campaign.

Attempts were also made to fortify ordinary white flour—not by adding synthetic vitamin B, as was done in Britain, but by incorporating wheat germ. This method of enrichment was successful only if the wheat germ was first treated by heating it in a vacuum to eliminate an oxidase known to destroy the vitamin if the germ was stored for any length of time. Wheat germ and white flour were supplied to forward troops in sealed metal drums. Though trials on the mainland proved that an excellent baker's loaf could be made from flour fortified in this way, experience in forward areas was not always so satisfactory. At the Milne Bay field bakery uniform success was attained; at some localities there was complete failure. On the whole, however, the bakeries seem to have been well run. After some inquiry the inconsistency of the results from different bakeries in the tropics was traced to a variation in the gluten, the component of flour which helped to maintain the sponge structure in baked bread. When the gluten content of flour was too low it was impossible to get the bread to rise. Australian wheats varied in gluten content from about 6 to 11 per cent. Moreover, the heat of the tropics did much to lower the gluten content during storage. The difficulty was finally overcome by specifying that flour for the army should contain not less than 10 per cent of gluten.[6]

[6] It was further specified that army bread should be made from an 80-85 per cent extraction flour —that is, one containing 80-85 per cent of the whole wheat grain.

A more radical solution to the problem of making bread rich in vitamin B was the practice dating back to the days of Alexander the Great of gristing wheat on the spot, near the bakery. A mobile steel gristing mill coupled to a Ford V8 engine mounted on a 5-ton truck was successfully operated at Camp Lee in 1944. Had field gristing of grain been adopted it would have avoided the hazard of the greater deterioration of white flour (as compared with that of wheat) that takes place in the tropics, and the expense of steel drums, but whether these advantages would have outweighed the obvious disadvantage of having to carry out the gristing in forward areas, was a question left unsettled. The scheme was never tried out in the South-West Pacific. Stanton Hicks drew attention to the need for further experiments on this subject, rightly taking the view that food and equipment for processing in the field were just as much legitimate subjects for military research and development as weapons were.

The standard of cooking in the messes studied by the party of scientists was high, though evidence from other sources showed that this was by no means universal. The keenness and efficiency of the field bakeries and of farm platoons, provided ample evidence that good work was done by the Army Catering Corps. An interesting commentary on the scope of the cooking was the report that "kitchens appeared to be adequately equipped except for a notable absence of mechanical can openers". That air crews were not receiving appropriate special rations drew an unfavourable comment: "Many flights begin soon after breakfast, which is much the least satisfactory of the meals at present provided, and the effects of this on the efficiency and morale were causing considerable concern to medical officers and others."[7]

Through the efficient work of the Air Maintenance Organisation, troops in inaccessible areas had supplies of food dropped to them from the air. They received a complete ration including fresh bread rolls, fresh meat, fruit and vegetables when these were available in the base areas.

The food of the average Australian soldier in the war of 1939-45 was more varied and generally of better quality than that of his counterpart in the war of 1914-18. In spite of the difficulties of production, transport and storage, servicemen in all theatres of war were fed surprisingly well. The soldier's diet was often more varied than the civilian's, and certainly more liberal. Demonstration of the fact that it was possible to maintain large bodies of men in reasonable health under tropical conditions provided a stimulus to a further study of one of the great problems still confronting Australia—that of occupying and developing tropical regions of her own continent and of New Guinea. One physiologist commented: "If these developments are allowed to lapse when hostilities are over it will be a cause for great national shame."[8]

During the first year of the war when Britain was making desperate efforts to build up her food reserves, Australia shipped to her foodstuffs

[7] Report of the Tropical Scientific Section, No. 3 (1945), p. 97.

[8] H. K. Lee, "Nutrition in the Tropics", *Aust Journal of Science*, Vol. 6 (1943), p. 6.

valued at approximately £45,000,000, which comprised about 73 per cent of the total food exports for the year. Australia continued to export food, principally to Britain, and by March 1943 the total value of this food had reached over £200,000,000.

In spite of every effort to increase production of food Australia could not meet all her commitments without restricting consumption of foods by the civilian population. For the first time since the earliest days of the settlement in New South Wales it became necessary to ration food, beginning with tea on 6th July 1942. Rationing was gradually extended to include sugar (31st August 1942), butter (7th June 1943), and meat (17th January 1944). The system was based on two principles: (1) to distribute equitably among the civilian population foods (or other materials) in short supply; (2) to curtail consumption so that the Commonwealth could help feed (and clothe) her allies. Savings effected by rationing are shown in the accompanying table.

	Annual civilian consumption			
	Tea million lb	Sugar '000 tons	Butter '000 tons	Meat '000 tons
Average for 3 years ended				
1938-39	47.3	344	101.0	760
1943	38.7	311	96.5	671
1944	39.2	305	80.7	624
1945	43.6	316	78.5	589

Source: Commonwealth Year Book No. 36, p. 1090.

The scale of rationing was not so severe as in Britain, where the monthly ration of meat and butter was equal only to the Australian weekly ration.[9]

Commonwealth Food Control, hampered as it was by wartime shortages and restrictions, did not of course solve all the problems of production and distribution of food. It is true that there were gluts of fruit and vegetables during the period of its activity, but it is equally true that there were even bigger gluts during the economic depression of the early thirties when many Australians went hungry. During the war years more food was produced and less wasted, and fewer Australians went hungry than at any other time in the country's history. Despite the fact that a large proportion of her most active young men were in the Services, Australia supplied more food per head of population to the Allied larder than

[9] The Australian rations were:
Tea, ½ lb per person for 5 weeks (increased to ½ lb per person for 4 weeks from 23 Nov 1942);
Butter, ½ lb per person per week (reduced to 6 oz per person per week from 5 Jun 1944);
Sugar, 1 lb per person per week;
Meat, average 2¼ lb per person per week (reduced by 8⅓ per cent 26 Feb 1945 and 12½ per cent 7 May 1945).

did any other country.[1] In September 1944 the United States Foreign Economic Administration reported that

> Australia and New Zealand have provided as reverse Lend-Lease over 95 per cent of all the food used by our forces in the Pacific Area under General MacArthur's Command.

As the number of American troops in the area increased this percentage fell, and for the year 1944 was nearer 50 per cent, which was still a notable contribution. Details of the quantities of major food items produced by Australia in the years 1943, 1944 and 1945 are given in the accompanying table. The great drive for food was a national effort by people of every class and occupation, but above all by the hard-pressed farmers "forced to endure unprecedented shortages and difficulties and yet asked to achieve unprecedented levels of production".

The general result of the impact of war on the Australian food industry was to awaken it to the significance of food technology. The rapid growth of the Institute of Food Technologists in the United States about this time and the growth of university courses in food technology in that country so interested many Australians associated with the food industry that the N.S.W. Branch of the Royal Australian Chemical Institute formed a food technology group in 1944. In the following year this group, working in conjunction with the Extension Board of the University of Sydney and with the Sydney Technical College, arranged a series of lectures on food technology to which many of the senior American food technologists contributed. The enthusiastic reception given to the course led to the starting of others and to the formation in the same year of the Food Technology Association of N.S.W. In some respects the changes taking place repeated the story of food technology in the United States, though on a smaller scale. Similar associations were soon formed in all States of the Commonwealth, and were linked together in a Council of Food Technology Associations which founded the technical journal known as *Food Technology in Australia.*

A number of Australians who had become members of the American Institute of Food Technologists took advantage of the close liaison with Dr C. E. Norton to begin negotiations on his return to the United States for the formation of an Australian regional section of that body. When Norton came back to Australia some years after the war as director of the Southern Can Company (Australia) Pty Ltd, an inaugural meeting was held in Sydney on 29th May 1950 and in the following September the Australian Section (No. 19) was chartered: the first section to hold a charter outside the United States. The counterpart in the academic world to the growth in the organisation of food technologists were the courses in food technology inaugurated in 1949 at the N.S.W. University of Technology and in the following year at the Hawkesbury Agricultural College in New South Wales.

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[1] Authority for this statement is given in an unpublished address by G. J. Evatt, Dir-Gen of Food Supply, C'wealth Food Control (1944).

QUANTITIES OF MAJOR FOOD ITEMS SUPPLIED FROM DOMESTIC PRODUCTION

Unit: '000 tons

	Aust, British and U.S. Services				Exports				Civilian consumption			
	1943	1944	1945	Total for 3 years	1943	1944	1945	Total for 3 years	1943	1944	1945	Total for 3 years
Dairy products (excl fresh milk)	30.9	36.4	28.0	95.3	64.6	51.8	59.2	175.6	112.0	101.6	96.5	310.1
Meat	207.0	216.2	216.5	639.7	138.0	134.1	143.5	415.6	671.0	592.6	540.0	1803.6
Jams, Canned and dried fruit	66.3	62.6	61.5	190.4	83.4	71.6	63.3	218.3	75.3	90.1	74.6	240.0
Sugar[2]	46.0	66.0	70.0	182.0	100.0	126.0	210.0	436.0	385.0	390.0	390.0	1165.0
Eggs[2]	14.5	16.8	17.3	48.6	2.4	1.2	8.5	12.1	40.0	51.6	51.2	142.8
Potatoes[3]	108.0	91.0	114.0	313.0	—	—	21.0	21.0	241.0	350.0	433.0	1024.0
Canned vegetables	30.3	36.9	30.6	97.8	1.8	—	44.4	46.2	—	1.1	—	1.1
Margarine	8.7	13.4	8.8	30.9	4.3	—	3.1	7.4	15.0	18.6	18.6	52.2
Flour, rice and oatmeal	134.5	162.2	111.0	407.7	361.5	672.7	205.4	1239.6	588.0	619.7	628.6	1836.3

[2] Figures for July-June years.

[3] Figures for November-October years.

1945 figures are estimates based on information available at 31 Oct.

CHAPTER 26

VITAMINS, DRUGS AND OTHER FINE CHEMICALS

IF one lesson emerges more clearly than almost any other from warfare in past ages it is that the power of disease may be more destructive than the clash of armed force. Such diseases as typhus, plague, dysentery and malaria have, throughout history, often decided the course of a campaign. Today, even though they have yielded to a high degree of control in civilised communities, these diseases are still likely to flare up in the disorganised living conditions of war. In the Pacific theatre during the five-month period between September 1943 and February 1944, the ratio of battle casualties to those caused by malaria, dengue fever, dysentery, scrub typhus and skin diseases was one to fifteen.[1]

With the unmistakable signs of approaching war and this age-old health problem in mind, medical authorities began towards the end of 1938 to give serious attention to organising their profession, forming for this purpose a body known as the Central Medical Coordination Committee. Through the efforts of a sub-committee of this body, the organisation of medical supplies in the event of war was well in hand by 1939. In order to make certain that there would be adequate supplies of drugs and medical equipment for the Services, this sub-committee was in August 1940 separated from the parent body, and given independent status as the Medical Equipment Control Committee (M.E.C.C.) under the Department of Defence. To enable it to fulfil its functions satisfactorily it was endowed under the National Security (Medical Coordination and Equipment) Regulations with powers

(*a*) to make orders for regulating, restricting and prohibiting the manufacture, production, storage, distribution, sale, purchase and use of medical equipment (which included drugs);

(*b*) on behalf of the Commonwealth to purchase, store and sell or otherwise dispose of medical equipment.

The chairman of the committee[2] had power to require any person carrying on a trade or business relating in any way to medical equipment (including drugs) to answer any question put to him and to furnish if required information concerning estimates and returns from his business. In short, the committee was given authority appropriate to its functions though it rarely had occasion to invoke these powers to their fullest extent.

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[1] G. Lapage, *Parasitic Animals* (1951).

[2] Membership of the Medical Equipment Control Committee when first constituted was: Lt-Col F. Kingsley Norris (for the Defence Forces), Chairman; Dr M. J. Holmes (Dept of Health); Lt-Col G. C. Rowe (Dept of Supply); J. W. B. T. Paton (Dept of Trade and Customs); Dr B. L. Stanton (British Medical Association); G. G. Jewkes; F. C. Kent (Sec, Pharmaceutical Society of Vic), Secretary. Mr Kent was succeeded in 1942 by Mr F. W. Ritchie, who was seconded from Parke Davis and Co Ltd. Ritchie's extensive knowledge of the items of medical equipment and of features of significance in commercial dealings in the trade, contributed materially to the success of the committee.

The committee was fortunate in having as its first full-time chairman Colonel Sir Alan Newton,[3] who held this post until November 1945. One of Australia's most brilliant surgeons, and a man with extraordinary gifts for organisation, Newton brought to the task wide technical knowledge and tremendous energy. There could indeed have been few men better fitted to undertake this important work. On his own admission, the committee functioned on somewhat unorthodox lines.[4] It was not, he said, a body which met in solemn conclave at regular intervals, a procedure which though time honoured he regarded as time wasting. In place of formal meetings there were daily conferences, telephone talks and teleprinter messages linking its members together. The committee surrounded itself with panels of advisers on different technical subjects and planned its courses of action with much foresight.

Since by far the greater part of Australia's medical supplies were then obtained from overseas, one of the committee's first jobs was to increase the stocks of equipment which the Department of Health had already begun to accumulate before the outbreak of war. The original plan was to do this by importation, refraining as far as possible from placing importunate and unreasonable demands on Britain and the United States. It was mainly through Newton's drive and energy that the committee was able to enlist the cooperation of all the commercial firms engaged in handling drugs and other medical equipment, ranging from wealthy wholesale houses down to tiny, isolated country pharmacies and stores. He was able to persuade large business houses to pledge their credit to the limit in building up essential imported medical items. Cooperation between business houses and the committee was so well developed that it was possible to ration drugs in short supply by a system of voluntary arrangements between the houses themselves and without written agreements or mandatory action by the committee. In thus securing full and effective cooperation between the committee and commercial firms, the Services, government departments, doctors, pharmacists and dentists, Newton so successfully directed the building up of stocks that there were no disastrous shortages even upon the entry of Japan into the war. There were grave anxieties about one or two drugs but as a general rule supplies were sufficient to tide the country over the period needed for chemical industry to get under way.

Though medical equipment covered a great many items besides drugs, it is with the latter that this chapter will be concerned. To begin, it will be necessary to turn back for a moment to the formation of another committee that was to work very closely with the Medical Equipment Control Committee. This was the Drug Sub-committee of the Australian Association of Scientific Workers, which began by holding weekly meetings in

[3] Col Sir Alan Newton, MB, MS. (Served 1st AIF.) Consulting Surgeon AHQ 1940-42; Senior Hon Surgeon, Royal Melbourne Hospital; President, Royal Aust College of Surgeons. B. 30 Apr 1887. Died 4 Aug 1949.

[4] Sir Alan Newton, Syme Triennial Lecture: "Control of Medical Equipment in a Nation at War", *Medical Journal of Australia* (1944), p. 101.

the University of Sydney as early as September 1939.[5] In its first approaches to the M.E.C.C. the Drug Sub-committee received little encouragement since the former body was then preoccupied with the problem of building up stocks of drugs by importation, while the latter was more interested in the possibility of promoting local manufacture. Nothing daunted, one of the first tasks to which the sub-committee addressed itself was the publication in 1940 of a List of Drug Synonyms and Trade Names[6] which was edited by Dr Albert.[7] This was very useful when the supply of branded medicines, many of which had come from Germany, was seriously disorganised. Later in 1940 the sub-committee renewed its approaches to Newton, who still held the view that it was his duty, as long as the sea lanes from Europe and the United States remained open, to import drugs to Australia rather than strain the country's undeveloped organic chemical industry by forcing it into premature activity. While agreeing with the general soundness of Newton's plan, the sub-committee felt that, in the event of the closing of the sea lanes, local chemical industry would be in no position to go immediately into the production of drugs which had never previously been manufactured on a commercial scale in Australia.

At this time, it will be recalled, important changes were taking place in the chemical industry which would make it possible to produce some of the primary and secondary, or intermediate, chemicals without which drugs could not be made. Aware of these developments, the sub-committee held to the view that Australian manufacturers would not be free for some time to devote their energies to mastering the intricacies of modern synthetic drug production, however great the need, and that much laboratory work must precede commercial production. It therefore ascertained the names of drugs which were likely to be required and whose manufacture appeared feasible.

Since members of the sub-committee also held full-time positions and could therefore serve only in their spare time and in an honorary capacity, it became necessary, if detailed laboratory investigations were to be carried out, to secure financial and technical assistance. This was obtained from the Research Committee of the University of Sydney, which made available some of the funds placed at the university's disposal by the Commonwealth Government. With this money a team of research assistants, mainly young science graduates, was gradually built up and several full-time investigations were begun under the direction of the sub-committee.

From March 1941 onwards the M.E.C.C. began to encourage the production of drugs in Australia and to make more and more use of the Sydney sub-committee's work. It gave highly necessary assistance in the

[5] Its first members were: Mr W. Lockwood (convener) and Dr R. Lemberg, Medical Research Institute, Royal North Shore Hospital, Sydney; Prof J. C. Earl, Dr A. Albert, and Dr D. White, Dept of Organic Chemistry, Univ of Sydney; Dr V. M. Trikojus and Dr A. Abbie, Dept of Medicine, Univ of Sydney; Dr C. B. Cox, C'wealth School of Public Health and Tropical Medicine, Univ of Sydney.

[6] The cost of publishing the list was borne by the Pharmaceutical Association of Aust and NZ, and of distributing the booklet by the British Medical Association and the Pharmaceutical Assocn.

[7] A. Albert, DSc, PhD. Research and teaching staff, Univ of Sydney, 1938-47; Adviser on Medical Chemistry, Army Medical Directorate, 1942-47; Prof Medical Chemistry, Aust National Univ, since 1949. B. Sydney 19 Nov 1907.

way of priorities for laboratory apparatus and materials. In return it took over the processes worked out by the sub-committee and arranged for them to be put into commercial operation. This as a rule involved constructing a small-scale or pilot plant on which the firm concerned might still have to do further research and development before passing on to large-scale production.

Although a sufficiently large stock of drugs had been built up to tide Australia over the period of confusion that followed the outbreak of war in the Pacific, the serious threat to communications that followed this event, plus the need for continuing to build up supplies, made it imperative to begin the synthetic drug industry in Australia.

One of the early investigations put in hand by the sub-committee was the working out of a process for the synthesis of vitamin C (ascorbic acid), the anti-scurvy vitamin. It was recognised that army rations should be fortified with vitamin C especially as tests in Australia and in the Middle East showed that bodily saturation with this vitamin was not always attained.[8] Vitamin C, the first of all the vitamins to be made in the laboratory, had been produced commercially on a large scale in the United States in 1937. It could most readily be made from chemically pure glucose (dextrose) as the starting material, and this fortunately was being commercially produced for the first time in Australia by W. Hoadley in Melbourne, who operated a makeshift plant under financial difficulties. Hoadley approached the M.E.C.C. for assistance. This was granted through the Department of Supply and enabled him to put on the market glucose sufficiently pure for intravenous injection. Hoadley's business was later acquired by Glaxo Pty Ltd, which continued to honour Hoadley's undertaking. Glucose, of medical importance in itself, was to prove most useful in the production of vitamin C and also, much later, of penicillin.

The laboratory synthesis of vitamin C was undertaken by Mr Cortis-Jones,[9] working in the section of Medical Chemistry in the University of Sydney under the direction of Dr Trikojus. Glucose had to be subjected to at least seven successive chemical processes before its conversion to the vitamin was completed. In the first of these glucose was subjected to the action of hydrogen catalysed by nickel under pressure. In spite of the help given by the M.E.C.C. it took many months to have this pressure equipment manufactured. The second step, consisting of a fermentation process,[1] was effected by a particular species of acetic acid bacterium (*Acetobacter suboxydans*), which Professor Ward[2] arranged to be imported by air from the United States. Except for a difficult period when the bacteria temporarily lost their powers of chemical synthesis owing to the lack of some

[8] Some reports stated that Australian troops in the Middle East suffered from incipient scurvy but the Medical War Historian, Dr Allan S. Walker, doubts their accuracy. See C. E. Napier, "Vitamin C. Its Production and Use in the Fortification of Foods", *Aust Chemical Institute, Journal and Proceedings*, Vol. 13 (1946), p. 19.

[9] B. Cortis-Jones, MSc. C'wealth Research Fellow 1940-42; Research Chemist, Colonial Sugar Refining Co Ltd, since 1942. Of Sydney; b. Sydney, 28 Mar 1913.

[1] Help in this phase of the process was given by Mr Hartigan, Chief Chemist of Tooth's Brewery.

[2] Lt-Col H. K. Ward, MC; MB. (Served RAMC in first world war.) Asst Prof Bacteriology, Harvard, USA, 1926-34; Bosch Prof of Bacteriology, Univ of Sydney, 1935-52. B. Sydney, 17 Sep 1887.

unknown growth factor, the laboratory work proceeded smoothly and the synthesis, by no means an easy one, was successfully completed. In the middle of 1943, at the request of Newton, the Drug Sub-committee handed over all the details of the process to the Colonial Sugar Refining Co Ltd (Sydney).

The company engaged Cortis-Jones to see the vitamin into large-scale production. As a means of stimulating production the M.E.C.C. had placed with the company an order for 100 pounds of the vitamin at a price, fixed by the Prices Commissioner, of £20 per pound. Soon after the first batch was completed the army placed an order for 8,500,000 tablets (475 pounds). This step was a timely one because it enabled the vitamin to be supplied to troops in the Pacific Islands. As a gesture of sympathetic cooperation with a sister Dominion the first output was sent to New Zealand troops, who appeared to be in more urgent need of supplies. In all more than 3,000 pounds of vitamin C were supplied to the army in the form of fortified foods or tablets (amounting to 50,000,000). Vitamin C was added to canned fruit juices, spreads and sweets included in army field ration packs. By the middle of August 1945 when production had reached 150 pounds per week, about 20 per cent of the output became available for civilian use. Its growing popularity as a substance for fortifying and preserving foods (as an anti-oxidant) ensured continuity of production of vitamin C after the war.

Several years before the war investigations conducted by officers of the C.S.I.R. Fisheries Division had demonstrated that oil derived from the livers of sharks abounding in the waters of the southern coast of Australia was rich in vitamin A—much more so than cod liver oil, hitherto the principal source of world supplies of this vitamin.[3] At that time no laboratory process for making vitamin A had been discovered. With the fall of Norway to the Germans in 1940 one of the most important sources of vitamin A was lost to the Allied nations. This induced the M.E.C.C. to take steps to foster a shark oil industry, and it was not long before the firm of Nicholas Pty Ltd began extracting the vitamin from sharks' livers on a commercial scale. For a while there was an exportable surplus but increasing local demand and the call up of fishermen for the Services soon reduced this to zero. As the United Kingdom was particularly anxious to obtain supplies of vitamin A, the M.E.C.C. took steps to remedy the position by arranging for sufficient fishermen to be allowed to carry on their work. Excessive consumption of vitamins by civilians still remained as a continuance of pre-war placebo prescribing and attempts were made to reduce this wasteful practice.

During the war one firm alone supplied over 8,000 gallons of shark liver oil vitamin A concentrate to the army in the form of fortified margarine, enriched chocolate, and other foodstuffs. A serious shortage of vitamin A oils existed throughout the Allied nations in the years 1943-45; Australian production not only met all civilian requirements and those of

[3] Shark liver oil is, on the average, about 15 times richer in vitamin A than cod liver oil.

the armed Services, but permitted the export of large quantities to India for the use of the armies in Burma.

The synthesis by two Germans, Metzsch and Klarer, of the first sulphonamide drug, known as "Prontosil", and the discovery of its therapeutic properties by their colleague, Domagk, marked a new era in the treatment of diseases caused by bacteria. Domagk discovered that "Prontosil" given in their diet protected mice against what would otherwise have been a fatal dose of streptococci. Soon afterwards French biochemists (M. and Mme Trefouël, and Mm. Nitti and Bovet) suggested that "Prontosil" owed its therapeutic action to the fact that in the body it broke down to form the simple substance sulphanilamide. This was rapidly confirmed by Fuller, a British scientist. Then followed the synthesis of a whole host of sulphonamides (known popularly in the United States as the "sulpha" drugs) all based on the sulphanilamide molecule, in the hope of obtaining improved effects or of extending the effective scope of this treatment to other diseases. Each drug had its own peculiarities; some proved better than others for treating certain disorders. Astonishing successes were obtained and the potentialities of these drugs were being widely exploited in many countries as the second world war broke out.

Until November 1942 Australia was entirely dependent on oversea sources for the supply of sulphonamides. Wherever practicable, stocks had been built up, but when further supplies appeared to be in danger and stocks began to diminish, the M.E.C.C. gave serious consideration to the question of their local manufacture. The firm of Monsanto Chemicals (Australia) Ltd was approached early in 1942 and persuaded to undertake the manufacture of sulphanilamide. The opportunity was a favourable one since a survey of raw material supplies disclosed that the Australian chemical industry was now able to provide in adequate amounts all the basic chemicals required: ammonia (from I.C.I.A.N.Z., Victoria), aniline (from Timbrol, New South Wales), alcohol (from C.S.R., Queensland) and chlorosulphonic acid (from Commonwealth Fertilizers, Victoria). Having given an undertaking that sulphanilamide would be in production within six to nine months, Monsanto began as soon as possible to install plant designed and made locally. In August 1942 the plant was ready for operation and within three months the first batches of sulphanilamide powder were ready for conversion to tablets. In the meantime, however, a much more urgent demand arose for another of the sulphonamide drugs, sulphaguanidine.

The scientific battle fought in the tropics was waged not only against moisture and moulds (as related in Chapter 24), but also against a number of widespread disease-producing micro-organisms, the most notable being malaria, dysentery and scrub typhus. Bacillary dysentery, which had caused crippling losses among troops in the 1914-18 war, was also a great waster of men in some campaigns of the 1939-45 war, particularly in the Owen Stanleys and in the Wau-Salamaua area. It was active in the Middle East right from the beginning. By the end of 1941 a con-

siderable body of medical scientific evidence had been accumulated by Colonels Fairley[4] and Boyd[5] in the Middle East, and by Marshall in the United States, that sulphaguanidine was an effective drug for the treatment of dysentery and was particularly valuable because of its low toxicity. The Australian army was the first to adopt sulphaguanidine as a specific for dysentery. At the beginning of the campaign in New Guinea when outbreaks of this disease threatened, there was no sulphaguanidine in Australia apart from some small supplies brought back from the Middle East, and there was little hope that it could be produced on a commercial scale in a short time. Fortunately two chemists at the University of Sydney were able to bridge the gap.

Dr Trikojus and Mr Hughes,[6] working in shifts almost literally day and night, improved a method of synthesising sulphaguanidine on a laboratory scale, sufficient to meet the immediate needs of the forces in New Guinea. Commercial production did not lag far behind. Monsanto Ltd had in fact considered the problem of making sulphaguanidine before the Japanese came into the war but had stayed its hand until the manufacture of sulphanilamide itself was under way. Once sulphanilamide was available in large quantities Monsanto Ltd was in a position to make correspondingly large quantities of sulphaguanidine because the process evolved by Trikojus and Hughes involved as a final step the fusion of sulphanilamide with dicyandiamide. Much higher yields of sulphaguanidine were later obtained by a process discovered in the Monsanto laboratories.[7] Practically the whole of Monsanto's output of sulphanilamide was diverted to the production of sulphaguanidine. Installation of equipment designed to carry out this further step began in mid-October 1942 and it was hoped to deliver about 100 pounds within six weeks. Activities proceeded at fever pitch and once again by working around the clock the target was reached: 100 pounds of the purified drug was delivered to the army in the first week of November. This, together with the earlier material from the University of Sydney, enabled dysentery to be held in check in New Guinea. In the opinion of Sir Alan Newton, "If this drug had not been available there might well have been a very different end to the battle of Kokoda." From November onwards the drug was delivered to the Australian forces at the rate of 500 pounds a week. Early in 1944, at the request of the British Ministry of Supply and the Australian Department of Supply, arrangements were made for the manufacture of sulphaguanidine on a still larger scale, principally to meet the needs of the British forces in Burma and India. All told, something like 200 tons of the drug were supplied. Mon-

[4] Brig Sir Neil Fairley, KBE; FRS, MD, DSc. (Served 1st AIF.) Director of Medicine, AMF, 1942-45. Chairman, Combined Advisory Cttee to Gen MacArthur on Tropical Medicine, Hygiene and Sanitation, HQ, SWPA. Senior Physician, Hospital for Tropical Diseases, Univ College Hospital, London. B. Inglewood, Vic, 15 Jul 1891.

[5] Brig J. S. K. Boyd, OBE; FRS, MD. (Served RAMC in first world war.) Head of the British Army's Pathological Service in the Middle East, 1940-43, NW Europe 1944-45; Director of Pathology, War Office, 1945-46. Director, Wellcome Labs of Trop Medicine, 1946-55. B. 18 Sep 1891.

[6] G. K. Hughes, DSc. Lecturer in Organic Chemistry, Univ of Sydney, 1934-44, Senior Lecturer 1944-55. B. Adelaide, 27 May 1908. Died 10 Feb 1955.

[7] Australian patents, 119,702 and 119,703, G. Burges and R. Royer, 1943.

santo Ltd was one of the two really large producers of this drug in the world at that time. Its plant at Braybrook, Victoria, was the largest development in drug manufacture based entirely on private enterprise that occurred in Australia during the war.

Malaria was one of the major scourges of mankind. In the past it had destroyed entire populations and checked invading armies. Since it was especially rife in the tropics, the problem of controlling malaria among military forces operating in the malarious areas of Syria, New Guinea and the islands to the north was of the first order of magnitude. Anti-malarial drugs became as important as ammunition. Australian troops had suffered some casualties from malaria in Crete, but the disease did not become significant until the campaign in Syria. When war broke out in the Pacific and the Japanese seized the cinchona tree plantations of Java, which supplied 95 per cent of the world's requirements of quinine, the position became serious indeed. Quinine up to this time had defied all the skill of the synthetic chemist. Even when it was synthesised in the laboratory in 1944 by Woodward and his team at Harvard, the method used was too complex and difficult to put into commercial practice.

The standard method of treating malaria in the A.I.F. at the time of the New Guinea campaigns was by three drugs, used in sequence. For the first three days quinine was given; while it could not prevent or cure malaria it quickly suppressed the active symptoms and controlled the fever, by acting chiefly on the asexual form of the parasite in the blood, which caused the clinical manifestations of the disease. The action of atebrin[8] was similar, but as it could not bring the temperature down as rapidly as quinine, it was given from the fourth day of an attack for five days. A week after the attack had started a 5-day course of plasmoquine[9] and quinine began. The value of plasmoquine lay not in the treatment of the disease, but in its power to destroy the sexual form of the parasite and so reduce the possibility of a relapse. Atebrin was also used for its power to suppress malaria, and a follow-up course was adopted in which finally the dose of atebrin was fixed at 0.1 gram for six days each week for six weeks. Atebrin was a most useful drug for prophylaxis as it had the power to suppress a latent infection, and by preventing it from becoming overt was a valuable saver of manpower.

That the incidence of malaria was high in the early stages of the New Guinea campaign came as no surprise to the medical authorities. The only drug sufficiently plentiful for widespread use among the troops was quinine. Uncertainty about supplies of atebrin caused the gravest anxieties. The Sydney Drug Sub-committee made an intensive study of the published method of making atebrin with a view to cutting down the twenty different stages involved and adapting them to raw materials locally available, while at the same time maintaining the purity of the drug. Small amounts of atebrin were made by Albert in the laboratory, but its synthesis was

[8] Also called mepacrine, in Britain, and quinacrin in the United States.

[9] Also called pamoquin.

beyond the capacity of Australian industry of the period: to make 100 pounds of atebrin would have required about 7 tons of intermediate substances not one of which was being made in Australia. In the face of this unpromising situation there was little to do but hope for supplies from overseas. The army decided to send a mission, under Fairley's leadership, to Britain and the United States for the purpose of securing drugs and materials for the prevention and treatment of malaria. In order to help in the discussion of chemical problems and to make available to oversea laboratories a number of technical improvements in the preparation of atebrin that had been discovered at the University of Sydney, Dr Albert was appointed to accompany the mission.

Among the Allied nations the United States held the largest stocks of atebrin and certainly had the greatest industrial potentialities for producing more. For a while there was some hesitancy in the United States about producing more atebrin, because of reports that it might have toxic effects if used over a long period, and stocks were frozen.[1] This uncertainty was resolved at a meeting of American, British and Australian army and medical experts in Washington (September 1942), "where reassuring evidence was given by Brigadier N. H. Fairley and Professor Warrington Yorke".

There was little prospect of producing quinine locally. Early in 1940, in response to a request from the M.E.C.C., the C.S.I.R. began investigating the production of quinine from Australian-grown cinchona trees. It was realised that this investigation would take at least six years if the bark only of the tree was used, as was the current commercial practice, because it could be harvested only once in two years. The C.S.I.R. was encouraged to persist with the work by reports from the Soviet Union that it was possible to harvest the cinchona tree at an early stage and to treat it as an annual crop if the trees were planted closely and the whole plant was harvested.[2] Trees were planted in different parts of Queensland (Gadgarra, Nambour and South Johnstone) and by October 1943 prunings were taken and assayed by Mr Shaw[3] and his staff at the Department of Pharmacology, University of Melbourne. It was clearly evident that the conditions of climate and soil on neither the tablelands nor the coastal regions were suitable for the trees. Later, seedlings from high-yielding trees grown in the Philippines were planted at Aiyura, New Guinea, by Angau. When attempts were made to develop a small scale process for extracting quinine from the bark it was discovered that manufacturing firms in Java had published little except very general principles concerning their methods of extraction. A laboratory process was worked out and later expanded to a pilot scale, but no significant amounts of quinine were produced.[4]

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[1] Plasmoquine was also regarded by some Americans as too toxic for use but this view was later disproved by Australian experience.

[2] Australian results on the yields of quinine and other alkaloids from different parts of the plant agreed approximately with the Russian work: samples of whole-shoot prunings contained 1.1 per cent total alkaloids and of the bark alone 1.75 per cent.

[3] F. H. Shaw, MSc, PhD. Senior Lecturer in Pharmacology, Univ of Melbourne, 1940, Assoc Prof 1947, Prof since 1954. B. Hawthorn, Vic, 4 Jun 1910.

[4] By E. P. Keogh, Pty Ltd, South Yarra, Vic.

Alstonia constricta, known as "bitter bark" or "quinine bark", had the reputation in the Australian bush of being a febrifuge. When supplies of quinine were cut off by the Japanese occupation of Java, *Alstonia* was investigated as a possible cure for malaria, but it was found to have no anti-malarial properties.

Early in 1942, experiments being carried out in West Africa on British troops indicated that sulphamezathine showed more than usual promise as an anti-malarial drug. About this time Professor MacBeth[5] of the University of Adelaide was, with the help of funds provided by Imperial Chemical Industries of Australia and New Zealand, studying methods of making sulphonamides, though sulphamezathine was not one of them. Encouraged by the reports from West Africa, Newton invited MacBeth to explore the problem of making sulphamezathine. Before he had got far with the investigations further reports on the West African work referred to serious side effects of sulphamezathine which led to kidney damage.[6] The work was therefore abandoned, but research was directed instead to sulphamerazine, which was reported in the United States to possess favourable anti-malarial properties, and to have the important advantages of being rapidly absorbed and also of being easily excreted by the kidneys, thus lessening its toxic effects. The work of MacBeth and his team in Adelaide centred on the general chemistry of sulphamerazine and on efforts to improve the efficiency of the different stages of the manufacturing process. At Newton's instigation the Commonwealth Government arranged with I.C.I.A.N.Z. for the large-scale commercial manufacture of sulphamerazine. Before undertaking the large-scale operation it was necessary to develop MacBeth's laboratory process to an intermediate or pilot scale. Chemical engineers of I.C.I.A.N.Z., with some assistance from MacBeth, erected a pilot plant at Deer Park which in fact served a dual purpose—that of developing the process and at the same time manufacturing small supplies of the drug for clinical tests.

In the meantime work was proceeding on the large-scale manufacture of sulphamerazine. Owing to the urgency of the work and the general restrictions of wartime conditions, there was little opportunity to seek extensive technical aid from overseas or to import equipment. Translation of a laboratory process to the large scale was not as simple as it might sound; even at the pilot scale there could be, and in this instance there were, hitches of different kinds. Manufacture of a complicated drug was not simply a matter of mixing a number of ingredients and heating them together; in making sulphamerazine there were at least eight major processes involving the use of a great variety of chemicals such as benzene (from Broken Hill Pty Ltd, Newcastle), chlorine, ammonia, carbon-bisulphide (all made by I.C.I.A.N.Z.), pyridine (from Timbrol, New South

[5] A. K. MacBeth, CMG; MA, DSc. Lecturer on Organic Chemistry and sometime A/Prof of Chem, Queen's Univ, Belfast; Prof of Chem, Univ of Adelaide; Scientific Liaison Officer, Medical Equipt Control Ctee. B. Belfast, Ireland, 11 Aug 1889.

[6] These side effects can be produced by most sulphonamides though by some more than others. Subsequent work on sulphamezathine disproved earlier reports concerning severe kidney damage. The drug was very widely used in Burma because of its low toxicity in hot climates.

Wales), alcohol (from Colonial Sugar Refinery, Queensland), and formic acid and sodium, the only two which had to be imported.[7]

The complexity of the chemical operations involved in making sulphamerazine was such that it required a whole factory to make the drug. For six months a staff of draughtsmen, procurement and purchasing officers, construction engineers and research chemists worked every day of the week to complete the plant which was built as an annexe by I.C.I.A.N.Z. for the Commonwealth Government. One of the most impressive of the engineering achievements in the plant was the fabrication for the first time in Australia of the glass-lined equipment needed to handle the highly corrosive chemicals employed. The plant was completed by January 1944, within six months. Within a further three months production was well under way, and by the following December production reached its peak at over 4,000 pounds per month. To make one ton of sulphamerazine required 30 tons of raw materials. These in turn were converted to 10 tons of seven different intermediate substances; in processing the intermediates 15,000 gallons of solvent liquids were used.

In June 1943 an important research unit under the direction of Brigadier Fairley was established at Cairns, Queensland, for the purpose of investigating the whole question of the prevention and treatment of malaria, and of evaluating a number of anti-malarial substances, of which sulphamerazine was one.[8] Altogether 900 men volunteered for this work and most of them agreed to being deliberately infected on a number of occasions during the three-year period of the experiments. The selection of the volunteers was restricted to men who had never lived in a malarious area and who were organically sound, physically fit, mentally stable and had good conduct records. The practice of conducting anti-malarial research on healthy young soldiers instead of hospitalised mental patients began a new epoch and represented the largest and most thoroughly controlled piece of chemotherapeutic research done on any dangerous infectious disease. The experiments showed that volunteers exposed to heavy biting by mosquitoes and dosed with quinine were completely unprotected against malignant tertian malaria, and were afforded only 66 per cent protection against benign tertiary infections.[9] After much work it was found that although sulphamerazine had both preventive and curative properties against the malignant form it was only slightly effective against the benign form. None of the substances tested proved better than atebrin.

A highly significant discovery made by the research unit towards the end of 1943 was that soldiers given 0.6-0.7 gram of atebrin a week could be sent into the most dangerous malarial areas and be engaged in jungle fighting for many months without contracting malaria. Up to this time the official dose of atebrin had been less than 0.6 gram and malaria

[7] A full technical account of the production of sulphamerazine by L. W. Weickhardt appeared in the Australian Chemical Institute's *Journal and Proceedings*, Vol. 14 (1947), p. 81.

[8] For a fuller account of malaria and its treatment see *Clinical Problems of War* by Dr Allan S. Walker, in the medical series of this history.

[9] N. H. Fairley, *Transactions of the Royal Society of Tropical Medicine*, Vol. 40 (1946), p. 105.

had been taking a heavy toll. In the Kokoda-Buna campaign 5,816 Australians were killed or wounded while 21,600 were stricken with malaria. The verdict of the British War Office on atebrin was: "Its use in the 1939-45 war gave us great tactical advantage over the Japanese. We could operate in malarious areas which they had to avoid."[1] Though sulphamerazine did not live up to its original high promise as an anti-malaria drug, the research work done on it was by no means wasted. Such are the strange twists and turns that scientific investigation may take that speculations about the chemical properties of sulphamerazine led to the discovery of the drug paludrine, which proved superior even to atebrin.

Fortunately Fairley's mission to secure atebrin from the United States was successful and regular supplies reached Australian forces in the tropics. Australia's important contribution to the conquest of malaria lay not in manufacture but in research to evaluate the efficacy of anti-malarial drugs. The work of the medical scientist played no small part in bringing about victory in the Pacific.[2]

Sulphamerazine, although unsuccessful as an anti-malarial, proved to be one of the best of the general-purpose sulphonamides and in some respects superior to the imported sulphadiazine. Sulphamerazine filled the needs of the Australian Services in the treatment of diseases arising from streptococcal, gonococcal and pneumococcal infections.

There were other aspects to chemical warfare against malaria than the attack on the disease-producing parasite after it became lodged in the blood of its victim. The infective micro-organism of malaria (a protozoan) is conveyed from man to man by the *Anopheles* mosquito. The preventive phase of anti-malarial campaigns centred on the extermination or the repelling of the insect carriers of the disease. For the control of the early or larval stage of the mosquito it had long been the practice to spray breeding pools with petroleum oils or Paris green dust (copper aceto-arsenite). Both materials were used in New Guinea in the early days of the war. However the most effective substance in the control of mosquitoes was one developed later: the discovery in 1940 of the insecticidal properties of dichlorodiphenyl-trichloroethane (D.D.T.) by Mueller in Switzerland marked one of the most notable advances in the chemical control of insects.[3] Oddly enough the substance itself had been made and described more than 60 years before by a German chemist,[4] but it was only as a result of a more or less systematic search for an insecticide that its great usefulness as such was discovered. Mueller had been working on the problem of finding a poison active against the common clothes moth and was influenced by the well-known activity of chlorinated benzenes in this direction. Mueller's original idea had been to make use of the toxic

[1] *Memorandum on Medical Diseases in Tropical and Sub-tropical Areas,* War Office (1946).

[2] E. Ashworth Underwood, "Medicine, Surgery and their Scientific Development". A chapter in *A Century of Science* 1851-1951, written by specialist authors under the editorship of H. Dingle.

[3] Mueller's initial patent application was taken out on 7 Mar 1940.

[4] Zeidler, in 1874.

properties of chlorinated benzene and at the same time devise a molecule whose structure would permit it to attach itself to textile fibres. Though he did not achieve what he set out to do, he was ultimately led to the discovery of the extraordinarily powerful insecticidal properties of D.D.T. It is said that the United States authorities first heard of the insecticidal powers of D.D.T. through the censor of mails from Switzerland. Whatever the truth of this story, it is certain that by 1942 it had been tried out by the Bureau of Agriculture in the United States and at Rothamsted in England.[5]

Australian scientists were quick to grasp the potentialities of D.D.T. in solving problems of insect control. The three principal raw materials (chlorine, alcohol and benzene) were readily available in Australia, and in May 1943, soon after its reputation as a reliable, powerful and widely effective insecticide had been established beyond doubt, I.C.I.A.N.Z. began to manufacture it.[6] The first batch of 10 tons ordered by the M.E.C.C. was synthesised on a pilot plant which had been built for sulphamerazine. A large plant was designed and built at Yarraville to fulfil orders from the forces in the South-West Pacific. In view of the importance of insect control in the production of food, I.C.I.A.N.Z., with the permission of the M.E.C.C., gave several tons of D.D.T., both as such and as formulated products, to the C.S.I.R. Division of Entomology and to State departments of agriculture for investigations on the control of insect pests of food crops and animals. Very promising results were obtained against cattle tick, buffalo fly, and a number of household pests, including flies.

Because a concentration of only one part of D.D.T. to 2,000,000 of water was effective against mosquito larvae, it revolutionised methods of mosquito control, and was used extensively throughout the anti-malarial campaign undertaken in the South-West Pacific during the latter stages of the war. An effective kill of mosquitoes was obtained in jungle areas by spraying from aircraft an oil containing 5 per cent D.D.T. at the rate of two quarts and a half to an acre. This was in striking contrast with earlier methods, which used up to 20 gallons of untreated oil for each acre of water surface.

Even though D.D.T. was extraordinarily efficient as a larvicide, it was never possible to be certain, especially in places where every footprint in the mud might become a breeding ground, that all malaria carriers had been exterminated. A second line of attack was to use, in tents and huts, sprays incorporating pyrethrum extract[7] derived from the white flower of the daisy-like plant *Chrysanthemum cinerarifolium*.[8] For many years before the war Japan had virtually held the world monopoly of the production of pyrethrum extracts, until extensive plantations were developed in

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[5] Strange as it may seem, DDT was not used by Germany during the war. Some use was made of the less effective fluorine analogue.

[6] R. F. Cane, "The Manufacture and Application of D.D.T.", *Aust Chemical Institute Journal and Proceedings*, Vol. 15 (1948), p. 342.

[7] The active principle of the extract is known as pyrethrin.

[8] D. F. Waterhouse and Major D. O. Atherton, "Spray Tests against Adult Mosquitoes", *CSIR Bulletin* No. 219 (1947).

Kenya. However supplies from Kenya were limited, and the Allied nations became so short of this valuable insecticide that it was necessary to withdraw it entirely from civilian use and restrict it to mosquito control. This measure, together with the efforts of the C.S.I.R. Division of Plant Industry in establishing plantations of *Chrysanthemum cinerarifolium* in several parts of the Commonwealth, ensured that the requirements of the Australian armed forces were met.

One of the main problems in producing pyrethrum was the great labour of collecting the flower heads. Cheap labour had been an important factor in enabling the Japanese to secure their world monopoly and in the establishment of the industry in Kenya. Attempts to harvest the crop by means of a modified wheat stripper were not highly successful. Most of the plantings were made at prisoner-of-war camps where plenty of labour was available for harvesting by hand: bunches of flowers were cut by a sickle and the flowers were detached by means of a comb. From crops grown near Canberra under the direction of Dr Barnard[9] of the Division of Plant Industry some 26 tons of flowers were harvested. Unfortunately their pyrethrin content was rather low. To eke out supplies investigations were made of synergists, or activators—substances that were themselves only slightly toxic to insects, but which when added to pyrethrin produced effects greater than the sum of the effect produced by the two substances acting separately. Many essential oils from Australian plants were tested for effects of this kind, but without much success. Attempts by the C.S.I.R. to find strains of flowers more suited to harvesting by mechanical means were discontinued in 1945, mainly because even if the search had been successful the high cost of labour would have prevented the industry from competing with Kenya's. An additional discouraging factor was the commercial production of synthetic insecticidal materials closely akin to pyrethrin.

The efficacy of these and other chemical methods of controlling mosquitoes was greatly increased by the taxonomic work of a number of entomologists especially that of Lee[1] and Woodhill.[2, 3] Had this work not been done, much energy might have been squandered on the oiling and draining of swampy areas harbouring non-malarial mosquitoes. When war broke out in the Pacific the areas to the north of Australia in which malaria occurred were fairly well known, but the identity of the mosquitoes responsible for its transmission had not been adequately established. In northern Australia no vector had been determined, although the disease was endemic there. The war brought about a great increase in the knowledge of the distribution of different kinds of mosquito in this region.

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[9] C. Barnard, DSc. Principal Research Officer, CSIR Division of Plant Industry, since 1928. B. Kalgoorlie, WA, 6 Aug 1904.

[1] D. J. Lee, BSc. Entomologist, Qld Dept of Agriculture, 1937-42; Research Fellow, Scientific Liaison Bureau and Univ of Sydney, 1942-48. B. Sydney, 28 Jan 1915.

[2] Maj A. R. Woodhill, PhD. Lecturer in Entomology, Univ of Sydney; O i/c 1st Aust Mobile Entomological Unit. Of Sydney; b. Nowra, NSW, 21 Feb 1900.

[3] D. J. Lee and A. R. Woodhill, *The Anopheline Mosquitoes of the Australian Region*, Univ of Sydney, Dept of Zoology Monograph No. 2 (1944).
I. M. McKerras, "The Australasian Anophelines as Vectors of Malaria", *Medical Journal of Aust*, Vol. 1 (1947), p. 1.

Mosquitoes that survived larvicides and sprays were met with a final line of defence in the form of repellent substances applied to exposed parts of the body. Standard army citronella cream, which had been extensively used as a repellent in temperate climates, proved to be almost useless for this purpose in the tropics. In an effort to discover something better than citronella oil army authorities turned to the C.S.I.R. for help. The facilities of the Division of Economic Entomology at Canberra and the services of Mr Waterhouse[4] were promptly offered. What appears to have been an eminently satisfactory arrangement was made, under which Waterhouse was able to act in a dual role: while in the laboratories at Canberra he retained his civilian status, but when it became necessary for him to proceed to the forward areas to observe the effectiveness of measures adopted as the result of laboratory investigations, he became a freelance officer in the Australian Army Medical Corps, with the rank of captain.[5] This ensured that the results of successful laboratory tests were translated to the field of battle with the maximum speed and efficiency. The establishment of a relationship mutually satisfactory to the army and the scientist was a matter of the greatest importance. The nature of this relationship varied according to circumstances, and for this reason it is worth while to record an instance where it appears to have been successfully achieved. It was not always so.

In association with Major McCulloch,[6] an army entomologist, Waterhouse began an exhaustive series of tests on more than 100 substances, including many essential oils derived from Australian plants. Repellents were compared on the basis of the time between their application and the first bite, and also on the rate of loss of protective power after the first bite. No repellent was perfect; protection was a matter of degree. Many substances proved to be as repulsive to human beings as they were to mosquitoes, and caused skin irritations. One quite effective mosquito repellent, the oil of *Dacrydium franklinii* (Huon pine), when applied to the face, was apt to cause vomiting. In making their tests McCulloch and Waterhouse had no difficulty in securing the cooperation of many volunteers who, often with much personal discomfort, submitted themselves to the bites of blood-hungry female mosquitoes which were undaunted by inefficient repellents.

As a result of newspaper appeals for substances likely to be of use as repellents, the Vacuum Oil Company Pty Ltd submitted a proprietary repellent cream made by one of its subsidiary companies—Stanco (Australia) Pty Ltd—containing dimethyl phthalate as its active component. Tests made in Canberra in August 1942 showed that dimethyl phthalate (pure specimens of which had been made by Professor Earl at the

[4] Capt D. F. Waterhouse, DSc. Research Officer, CSIR Div of Entomology, 1938-53, Assistant Chief of Division since 1953. Of Canberra; b. Sydney, 3 Jun 1916.

[5] The army was never seriously worried about this alternation between service and civilian status, since theoretically it retained its control over Waterhouse at all times by placing him on the reserve list of officers.

[6] Maj R. N. McCulloch, MBE; DScAgric, BSc. Entomologist, NSW Dept of Agriculture, 1929-42; OC 3 Aust Mobile Entomological Section, 1942-45. Principal, Roseworthy Agricultural College, SA, since 1949. B. Urana, NSW, 8 Apr 1904.

University of Sydney) was the most effective of the large numbers of substances examined. Moreover it possessed the advantages of being practically odourless and without any irritating effect on the skin.

While these experiments were in progress members of the Australian Army Mission to the United States in 1942 were making inquiries concerning the results of similar investigations being carried out by entomologists of the Department of Agriculture at Orlando, Florida. On the strength of advice received concerning results of this work, the mission selected dimethyl phthalate as the most promising mosquito repellent. The information was duly sent on to Army Headquarters in Melbourne, where owing to some oversight it was held for some time instead of being promptly passed on to the Australian scientists concerned. This incident is mentioned not because it had any serious consequences (it did not), but because it illustrates what can happen to valuable information—collected at some cost—when liaison between scientists and the Services is poor. No question of priority was involved, nor was the work of the Australian scientists, carried on for some time in ignorance of what had been done in the United States, wasted. The independent findings of McCulloch and Waterhouse carried special weight with the army because they concerned the mosquito *Anopheles punctulatus*, the principal vector of malaria in the South-West Pacific Area. When the army came to make a decision on the use of dimethyl phthalate, it did so with a great degree of confidence in the light of these independent, but mutually confirmatory, investigations.

Production of dimethyl phthalate offered no serious problem to the chemical industry, especially since phthalic anhydride was by now being made by the Newcastle Chemical Company. Three firms[7] undertook the work and one of them reached an output of six tons a week by April 1943. Australian troops were using dimethyl phthalate in the field before the middle of the year. Troops who were severely exposed to mosquito attack between sunset and sunrise were ordered to use dimethyl phthalate, but for a number of reasons it was not always as effective as it might have been.[8] In some highly malarious regions biting was so imperceptible, and the nuisance effect of the mosquitoes so small, that when discipline concerning its use was not maintained the men failed to use the repellent. Sometimes insufficient repellent was applied to give the full protection of which it was capable, and this led the men to doubt its efficacy. These doubts were strengthened when mosquitoes were seen to hover over, alight on and even to bite treated skin. What the doubters did not realise was that for every bite they got in spite of the repellent, far greater numbers were prevented.

A minor disadvantage of dimethyl phthalate was that it dissolved many plastics, such as those found in unbreakable watch glasses, fountain pens

[7] W. Hermon Slade & Co Pty Ltd, Monsanto Chemicals (Aust), and Cox Finlayson & Co Ltd.

[8] R. N. McCulloch and D. F. Waterhouse, "Laboratory and Field Tests of Mosquito Repellents", *CSIR Bulletin* No. 213 (1947).

and spectacle rims. On the other hand, the men found that it had one unexpected advantage: it made an excellent substitute for brilliantine.

An equally, or perhaps even more important use of phthalates was against scrub (trombiculid) mites, the vectors of scrub typhus. As the fighting in New Guinea grew more arduous and the lines of evacuation became longer and more exhausting, mortality from this disease became alarmingly high. Soon after the efficiency of dimethyl phthalate as a mosquito repellent had been thoroughly demonstrated, a report came from the United States that it was also active against "chiggers" (mites which burrow under the skin). This immediately suggested to McCulloch that it might be worth trying against scrub mites. Experimenting first in safe areas in New South Wales, then on the Atherton Tableland (in Queensland), and finally in New Guinea, he was able to show that dimethyl phthalate not only repelled but killed these mites. Dibutyl phthalate, almost as effective as the dimethyl, possessed the great advantage of attaching itself much more tenaciously to fabrics. Why this should be so was not clear. The practical outcome, however, was that clothing treated with dibutyl phthalate retained sufficient, even after ten washings, to afford protection against mites.

Fortunately, at about this time (1943) butanol from the Weizmann fermentation process being operated by Robert Corbett Pty Ltd of Lane Cove, New South Wales, was more plentiful in Australia than methanol,[9] so that in adopting dibutyl phthalate against mites there was no need to reduce the amount of the dimethyl ester used in the anti-malarial campaign. Although malaria was the real danger and was far more widespread in the South-West Pacific Area than scrub typhus, the latter was more often fatal and the troops feared it more than any other tropical disease.[1] Once dibutyl phthalate was introduced the incidence of scrub typhus and the number of deaths from it fell dramatically.

In spite of the brilliant success of the chemist in synthesising substances found in plants and animals, some of the most useful ones remained beyond his skill.

Morphine, usually derived from a species of poppy (*Papaver somniferum*), was one of the most important drugs in the whole armamentarium of medicine, and no adequate substitute for it was known during the second world war. The seed capsule of this poppy on being incised yields a sap or latex known as opium, containing anything from 6 to 17 per cent of morphine. Medical consumption of opium in Australia before the war was estimated by the M.E.C.C. to be about 2,000 pounds a year, of morphine itself 7,000 ounces, and of codeine 3,000 ounces. Supplies came chiefly from the Balkans, Turkey and Iran. India, once an important source, ceased production under a League of Nations agreement in 1939 but resumed soon after war broke out. After the loss

[9] The synthetic ammonia-methanol units under construction by ICIANZ had not yet been completed.

[1] See Walker, pp. 177-201, for an account of the medical aspects.

of the Balkans, India was called on at short notice to supply the bulk of the Allied requirements. While production in India was getting under way a brief but critical period occurred when supplies in Australia were reduced to sufficient for only three months. This caused anxiety and gave point to Australian efforts to produce the drug.

Soon after its formation the M.E.C.C. prepared a list of essential drugs of plant origin and asked the C.S.I.R. to investigate the possibility of their successful production in Australia.[2] The investigation became the responsibility of the Division of Plant Industry, which early in 1940 began experiments to find out how to estimate the quantities of drugs in the plants, and the conditions under which the best yields of drugs could be obtained. Study of the opium poppy was one of the division's main preoccupations. As early as 1939 Mr W. R. Grimwade had imported poppy seed from England and had begun the experimental cultivation of the plant on his drug farm at Frankston, Victoria. The result was that when the firm of Felton, Grimwade and Duerdins Pty Ltd was asked by the M.E.C.C. to undertake the manufacture of morphine from poppy to be grown under the direction of the C.S.I.R., it was ready with a process using the latex that had been tested on a pilot scale.

Although cultivation of *Papaver somniferum* had for many years been illegal in all States of the Commonwealth, flowering varieties of this species could be bought from florists and seed merchants. It was in fact quite a common flower and could be found growing in many gardens in the Federal Capital itself. There was little difficulty in growing the plant in gardens in normal seasons, but large-scale cultivation during a dry spell was another matter. Apart from difficulty caused by dry weather the problem was not so much one of growing as of harvesting the crop. An immense amount of manual labour was involved in incising the poppy capsules and extracting the sap. Quite early it became evident that if Australian production was to succeed under the conditions of manpower shortage then prevailing, some less primitive method of harvesting and handling the crop was essential. While manual methods were used in the Balkans and some other countries attempts were made in Central Europe to harvest the whole plant, and processes for extracting the drug from the whole plant had been described in the patent literature.[3] Felton, Grimwade and Duerdins undertook to develop a method based on information supplied in the patents for extracting morphine from the capsule and stalk, and entered into an agreement with the Department of Supply and Development to provide the Services over a period of four years with some 5,000 ounces of morphine. A special building was erected for the work and the installation of the necessary equipment completed about the middle of 1943.

Under the direction of the Division of Plant Industry the opium poppy was cultivated with varying degrees of success in many parts of the

[2] The division also made a quick survey of Australian flora in the hope of finding useful species related to exotic drug-yielding plants, but nothing of any significance was revealed.

[3] First German patent 524,964. British patent 457,437, Switzerland 180,189. U.S.A. 2,132,945,

Commonwealth, including Griffith, Bathurst and Wagga in New South Wales, Mildura and Gippsland in Victoria, Lawes in Queensland, Margate in Tasmania, and Canberra. Prisoner-of-war camps at Loveday, South Australia, and Hay, New South Wales, also grew the poppy. There were some crop failures caused mainly by unusually dry seasons. On the basis of chemical analysis it was evident that the 1942 and 1943 crops (from all sources) would not provide the 5,000 ounces of morphine contracted for, and arrangements were made for storage of material (capsule and stalk) that had been harvested with a modified header harvester. Much of the very considerable analytical work needed for assaying the crop, which came from many sources, was carried out by Mr Finnemore[4] and his staff of the Department of Pharmacy, University of Sydney.[5] Analyses were also carried out by the chemists of Felton, Grimwade and Duerdins. Some unusually low yields of morphine were traced back to leaching of opium from the poppy by rains occurring while the crop was drying or after it had dried.

Only small amounts of morphine were produced during the war, and their cost was far above current market prices. Fortunately the critical position envisaged by the M.E.C.C. did not arise and Australia was able to maintain adequate stocks of morphine.

An attempt was made after the war, using the harvests gathered up to the end of 1945, to determine whether the manufacture of morphine could be made commercially successful so that the procedure would be established if the need should ever arise again.[6] Trial runs made in late 1946 and early 1947 on 86,000 pounds of the plant resulted in the recovery of 22 pounds of morphine, which represented an efficiency of extraction of approximately 30 per cent. At this point commercial manufacture of morphine ceased altogether, presumably because it was not economically feasible. There is some evidence that the growing of the poppy *Papaver somniferum* after the war was opposed by police authorities on the ground that it might increase the incidence of addiction, but it seems hardly likely that this was the real reason for the collapse of the industry.

For many years before the second world war Australian chemists had studied the occurrence and extraction of essential oils from indigenous plants, especially eucalypts, but very little had been done to investigate the presence of substances such as the alkaloids. Towards the end of the last century it was known that leaves of the corkwood tree (*Duboisia myoporoides*), which the aborigines threw into streams to stupefy fish,[7] contained a mixture of alkaloids.[8] These are naturally-occurring nitro-

[4] H. Finnemore, BSc. Reader in Pharmacy, Univ of Sydney, until 1946. B. Seighford, Stafford, Eng, 2 Apr 1878.

[5] Miss Jean Kimble was responsible for much of this work.

[6] The MECC did not from the outset ever expect that drugs like morphine would be made economically. In emergencies this would not have mattered.

[7] Another closely related species (*Duboisia hopwoodii*) was the source of the aborigines' masticatory "pituri", a crude extract used in the manner of the betel nut in Asia.

[8] J. Bancroft, *Journal of the Queensland Philosophical Soc* (1877), p. 1.

genous substances, usually of great physiological activity, of which strychnine is a well-known example. The German firm of Merck had marketed an extract from the leaves of this tree under the name of "duboisine sulphate" but had done very little work on the chemistry of the extract. As part of its wartime program, the Division of Plant Industry, in collaboration with the Departments of Pharmacy (University of Sydney) and Pharmacology and Physiology (University of Melbourne), made a study of drugs extracted from the corkwood tree, which grows in both New South Wales and Queensland. The leaves were found to contain at least two alkaloids: hyoscine and hyoscyamine.[9] Laboratory investigations by these organisations and the Developmental Division of Drug Houses of Australia Ltd, enabled Felton, Grimwade and Duerdins, in response to an urgent appeal from the M.E.C.C. on behalf of the army late in 1940, to accept an order for 6 ounces of the powerful drug hyoscine hydrobromide, which was administered in doses of one hundredth of a grain and was used as a sedative and for the prevention of sea and air sickness.

Everything went well with the pilot plant for extracting the drug from the leaves and within a month some 8 ounces were in the hands of army doctors. It was no longer necessary to import the drug since Felton, Grimwade and Duerdins were confident that they could keep pace with Australian needs. This confidence was fully justified, for from the end of 1941 onwards they not only satisfied local demands but exported many thousands of ounces of hyoscine to England and the United States. During the latter part of the war the drug was sent to England in 50-ounce lots by air and only one package was lost—when a bomb fell on the post office in London where it lay. Hyoscine from Australia was used to prevent sea sickness among troops at the landings in Normandy on D-day.

The occurrence of the second alkaloid, hyoscyamine, was also studied by the Division of Plant Industry. This alkaloid was usually found to be the preponderant one in another species, *Duboisia leichhardtii,* found in Southern Queensland. Trees yielding practically pure hyoscine, and others yielding almost pure hyoscyamine, were occasionally found among both species. Which alkaloid will preponderate seems to depend on the locality in which the tree grows. *Duboisia* growing north of Gosford, New South Wales, contained principally hyoscine; south of Gosford hyoscyamine was the main alkaloid. The importance of hyoscyamine lay in the fact that by a simple chemical process it could be converted into the valuable drug atropine, used for pre-operative medications. Felton, Grimwade and Duerdins used this process to make considerable quantities of atropine. Towards the end of the war a new factory was built, employing an improved method of extraction for the recovery of both alkaloids during the one series of operations. The collection and drying of the leaf, which required a good deal of organisation, became an important minor industry in Queensland. As a result of the wartime investigations Australia became the principal source of the world supply of hyoscine and atropine.

[9] The usual source of these drugs was henbane.

For a time the Government placed an embargo on the export of *Duboisia* leaves. When this was lifted several years after the war the local hyoscine industry gradually began to lose its pre-eminent position owing, it was said, to the high cost of labour in Australia. The success with *Duboisia* did, however, leave at least one permanent mark: it greatly stimulated the interest of chemists in Australian native plants as sources of pharmacological and insecticidal substances. In the decade following the war schools of research within the C.S.I.R. and the universities of Melbourne and Sydney made many interesting discoveries in this field. *Alstonia constricta,* known as "bitter bark" or "quinine bark", a tree mentioned earlier in connection with the wartime search for anti-malarials, was found to be a source of reserpine, a drug of considerable importance in the treatment of high blood pressure. Another interesting discovery was that of cryptopleurine (from the "poison walnut", *Cryptocarya pleurosperma*), a substance with some remarkable physiological properties. It is nearly as poisonous as strychnine, has a blistering action resembling that of the nitrogen mustards, and the ability, in small concentrations, to stimulate nerve regeneration.

Aesculin was another alkaloid extracted from an Australian plant (*Bursaria spinosa*), which was studied by Drug Houses of Australia. It has the property of absorbing the injurious ultraviolet rays of sunlight and emitting them as harmless visible radiations. In the form of a cream aesculin was tested on an experimental scale to see to what extent it gave protection from sunburn to pilots engaged in high altitude flying. It was not deemed worth while for use on any large scale.

For many years before the war Australian drug firms were accustomed to making up analgesic tablets from the drugs acetyl-salicylic acid, phenacetin and caffeine. Tablets containing acetyl-salicylic acid alone often went under the trade name "Aspirin"; those containing all three, under the name "A.P.C." The firms concerned in this work relied entirely on outside supplies of the last two drugs: caffeine from Holland, the world's principal supplier, and phenacetin from France. In the early years of the war acetyl-salicylic acid was still being made from imported salicylic acid and acetic anhydride; dependence on outside supplies of the latter continued,[1] but when early in 1942 Monsanto Ltd began the manufacture of synthetic phenol the way was open for the local manufacture of salicylic acid. This followed quickly and thus assured supplies of aspirin at a critical period. Over 80 per cent of Monsanto's wartime production of aspirin was acquired by the Commonwealth Government for the armed forces.

After both Holland and France had been occupied by the Germans, it became necessary to seek alternative sources of caffeine and phenacetin. Beckers Pty Ltd of Dudley Park, South Australia, took the initiative with regard to both. Having first explored the problems of manufacture on the laboratory scale with the help of Professor MacBeth Beckers began

[1] Adequate stocks of acetic anhydride had, fortunately, been built up.

commercial production of caffeine early in 1941, using as raw material cocoa beans from the African Gold Coast. Some of the theobromine extracted from the beans was set aside to meet demands; the remainder, which was by far the greater part, was converted to caffeine by the process of methylation. With the introduction of the manufacture of phenacetin early in 1944 Australia became self sufficient in regard to the ingredients of A.P.C. tablets, many millions of which were supplied to the medical organisations of the armed Services.

As a result of a fortunate accident to a bacteriological culture in 1929, Professor Alexander Fleming discovered that the mould *Penicillium notatum* generated during its growth a substance active against many kinds of bacteria. At first the substance, which came to be known as penicillin, appeared to be too unstable for easy isolation and identification, and the recognition of its value was delayed until 1940 when, under the stimulus of wartime needs Professor Florey,[2] one-time South Australian Rhodes Scholar, recognising that it might have great possibilities, organised at Oxford a team of scientists (including Ernst Chain, a refugee chemist) and began investigations. Chain worked out methods of extracting the drug from the mould without destroying much of the drug in the process, and it was not long before its importance in the treatment of bacterial infections was established. Penicillin has been described as the greatest British contribution to medicine since Harvey's discovery of the circulation of the blood. Trials in the North African campaigns demonstrated its extraordinary value in the treatment of war wounds.

Extraction of the drug from the mould on a large scale as first carried out in Britain was a most tedious process. Moreover British factories were so pressed with other work that prospects of manufacturing penicillin on a large scale were poor. Florey became convinced that the only way to exploit penicillin fully was to make use of the great technological facilities of the United States. On his advice the British Government asked authorities in the United States to do all they could to encourage the manufacture of penicillin. Thus it came about that the two countries pooled their resources and in the largest scientific combined operation ever undertaken proceeded to develop Fleming's discovery. Great progress was made in improving methods of extracting penicillin, and its manufacture on a large scale was well under way in the United States at the beginning of 1943.

Secret reports of the wonderful results obtained with the use of penicillin in the treatment of infected war wounds and other bacterial infections in North Africa and the United States were received by the Director-General of Medical Services in Australia. Medical and army authorities were unanimous on the desirability of trying to make penicillin locally, and it was decided that the attempt should be made by the Commonwealth Serum Laboratories. The laboratories immediately arranged to procure glassware

[2] Sir Howard Florey, FRS, MA, MD, BSc, PhD. Prof of Pathology, Univ of Sheffield, 1931-35; Prof of Pathology, Univ of Oxford, since 1935; Share of Nobel Prize for Physiology and Medicine 1945. B. Adelaide, 24 Sep 1898.

for the production of the drug. Captain Bazeley,[3] a biochemist and former member of the research staff of the Commonwealth Serum Laboratories, was sent to the United States to investigate the newest methods of manufacture. He arrived about eight months after the Americans had begun production and was given every help by the firms concerned. He brought back a new high-yielding strain of the mould, together with details of the method of assaying the drug by the cup-and-plate method.

While Bazeley was absent, the information contained in the reports he sent back enabled preparations to be made for the manufacture of penicillin at the Commonwealth Serum Laboratories. Founded during the war of 1914-18 when hospitals and medical practitioners were having great difficulty in obtaining supplies of anti-toxins from either Europe or the United States, these laboratories had expanded from a small organisation employing about 35 persons (in 1918) to one employing some 750 persons, including chemists, biochemists, physicists, botanists, bacteriologists, mycologists and engineers. In 1943 the laboratories prepared some 4,000 different varieties of sera, vaccines,[4] toxoids, endocrine substances, clinical and laboratory diagnostic agents, type cultures, culture media and many similar preparations. They had already rendered a service of great national importance in supplying millions of doses of preventive agents against tetanus, smallpox, plague, typhoid fever and cholera, not only to the Services and the civilian population of Australia, but to many other countries as well, including Palestine, Egypt, India, Burma, Malaya and Indonesia (until occupied), New Guinea and the Philippines.

On his return to Australia in January 1943, Bazeley set about organising the production of penicillin. The method adopted, a primitive one but the only one developed anywhere at this date, was to grow the mould in separate pint bottles, using at the first stage about 5,000 bottles. As production expanded the number of bottles used in growing each batch of mould rose to 26,000, and the total under cultivation at one time was 150,000. Originally it was expected that it would be about a year before useful quantities of penicillin could be produced, but owing to the high priority accorded to the project success was achieved in a much shorter time. The first supplies made available to the army, early in March 1944, were sent straight to New Guinea where they were used with great effect. From then on the laboratories contributed penicillin to the supply pool of the Allied Forces in the South-West Pacific Area, in which the United States forces shared. By the end of May 1945 limited supplies were made available for the treatment of desperately ill civilians.

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[3] Maj P. L. Bazeley, CBE; BVSc, MB, BS. Research Officer, C'wealth Serum Laboratories, 1939-40; Aust Armoured Corps 1941-44; AAMC 1944-46; Seconded to C'wealth Serum Labs 1943-46. B. Orbost, Vic, 2 Mar 1909.

In 1955 Bazeley took a prominent part in the initiation of the manufacture in Australia of the Salk vaccine for the treatment of poliomyelitis.

[4] A new achievement in this field was the development in collaboration with the Walter and Eliza Hall Institute of Research in Pathology and Medicine, of methods for the large-scale production of influenza-virus vaccine. The foundation of this work was laid by Dr F. M. (later Sir Macfarlane) Burnet, who succeeded Dr C. H. Kellaway as director of the institute in 1943. Burnet and his team conducted an extensive series of investigations on the cultivation of the influenza virus in the fluids of chick embryos. Within the next few years the institute's work on viruses gained for it a world-wide reputation.

The manufacture of penicillin in so short a time was a notable achievement, for which much of the credit must go to Bazeley, who with great energy and ability directed much of the work. Needless to say other officers of the Department of Health cooperated wholeheartedly, and the episode reflects great credit upon this Commonwealth department and its Serum Laboratories. Bazeley made a second visit to the United States in 1944 as a result of which, after the war, the whole penicillin plant at the Commonwealth Serum Laboratories was modernised to take advantage of deep culture of the mould in 5,000-gallon tanks, with continuous solvent extraction equipment and freeze-drying methods. With the experience gained with penicillin the laboratories were later able to undertake successfully the manufacture of other useful antibiotic substances such as streptomycin and aureomycin.

Production of the synthetic sedative phenobarbitone, or luminal, was one of the most ambitious undertakings in the field of organic chemistry—not because of the scale of operations so much as their complexity and the need for making many of the intermediate substances used. Twelve separate steps were necessary from the raw materials to the finished product. After some exploratory work by the Sydney Drug Sub-committee, Drug Houses of Australia took up the challenge, and although the war ended before full-scale production was attained the company made several tons of the drug, thus proving that its chemists and process workers were capable of making drugs of this class. Like a number of other ventures in this field of chemical industry the manufacture of phenobarbitone did not survive the economic competition of the immediate post-war period.

Notwithstanding the great success obtained with the sulphonamides and penicillin in the treatment of wounds, antiseptics continued to be used especially when the former, as they occasionally did, failed to give results. One such was proflavine, a substance that had been used as an antiseptic in field dressings in the war of 1914-18. Its synthesis had been thoroughly investigated and improved by Albert in the University of Sydney some time before the outbreak of war in 1939, and when the need for supplies became urgent semi-technical equipment there was pressed into service. Improvements were made in the purification of the drug by a procedure based on its crystallisation from water well above its normal boiling point.[5] Operating with an output of about 20 pounds a week, the university laboratory made available to the Services over half a ton of proflavine sulphate.[6] At the end of the war the whole process was transferred to a commercial plant (Timbrol Ltd).

Extensive investigations were made by Dr Albert and Professor Rubbo[7] at the Universities of Sydney and Melbourne on the chemotherapy of other

[5] This process had the advantage of avoiding the use of organic solvents and was patented by Professor J. C. Earl.

[6] Most of this work was done by Dr Conrad Gibian.

[7] S. D. Rubbo, PhD, MD, BSc. Senior Lecturer in Bacteriology, Univ of Melb, 1937-44, Prof since 1945. B. Sydney, 11 Sep 1911.

drugs closely related to proflavine. One of the most useful substances brought to light as a result of this work was 5-aminoacridine, later known under the trade name of "Monacrin". It was first made on a pilot scale by Mr Falk,[8] a member of the Drug Sub-committee's research staff. When a demand for the drug arose in one of the military base hospitals, its large-scale manufacture was entrusted by the M.E.C.C. to the firm of Bayer Pharma Pty Ltd. It soon won a place in the British Pharmacopoeia under the name "Aminacrine" and became a common component of first-aid dressings. Both proflavine and aminacrine had the advantage that they seldom caused drug sensitivity or allergy, a phenomenon by no means rare with the sulphonamides and penicillin; for this reason they were sometimes used when the latter were unsuitable.

A considerable number of drugs and similar substances were manufactured in university laboratories to meet emergency demands, notably procaine, mersalyl, merthiosal and eumydrin. It would be impossible to list all the drugs in this category but one or two examples will be chosen of attempts to anticipate needs that fortunately did not arise. There was always the possibility, for example, that the enemy would resort to the use of poison gases, and ordinary prudence called for preparedness with anti-gas measures. Lewisite, an arsenical compound, was one of the most feared of gas-warfare agents. To meet this danger British scientists had, in the early part of the war, developed a substance which would successfully block its effects. Having deduced that the toxic effects of Lewisite were exerted by its reacting with certain essential groupings in enzyme molecules present in the body's tissues, a team of biochemists at Oxford prepared substances with features of molecular structure similar to those complex enzymes, in the hope of finding one which would interact more vigorously with Lewisite than did the enzymes themselves. In this way the enzymes could be protected from Lewisite.

Among the substances they made was one that proved to be particularly effective and which became known among the Americans as British Anti-Lewisite (BAL), a name that was generally adopted as an alternative for its much longer chemical name. Although only the barest details on how to make BAL were available at the time, Mr Brown,[9] a postgraduate chemist at the University of Sydney, succeeded in devising a method which as events proved was different from that used in British factories. Fortunately BAL was not needed. Supplies of BAL made in the Organic Chemistry Department of the University of Sydney were used mainly in research on biological problems. In one emergency after the war some of the material was sent to a leading hospital for urgent treatment of a case of arsenical poisoning, with successful results. Further research in Britain and the United States established BAL as a most useful antidote in cases of poisoning by mercury and gold.

[8] J. E. R. Falk, PhD. Research Fellow Univ of Sydney and later Univ College Hospital Medical School London. Of Sydney; b. Cessnock, NSW, 22 Aug 1917.

[9] D. J. Brown, MSc, PhD. Research student in Chemistry, Univ of Sydney, 1942, research assistant 1945-46; Fellow Dept of Medical Chemistry, Aust National Univ. B. 16 Dec 1920.

Another substance made on a small scale in readiness for more extensive production should the need arise was acaprin, then obtainable only in Germany. It was the only specific known for the fatal tick-bite fever in cattle, a disease caused by a protozoon injected with the tick's saliva. Dr Reuter[1] of the Sydney Technical College was successful in making some 10 pounds of the drug.[2] Had tick fever become serious enough to threaten meat supplies, sufficient acaprin was provided to bridge the gap between small-scale and large-scale production.

[1] F. H. Reuter, PhD. Lecturer in Organic Chemistry, Sydney Tech College, 1938-52; Assoc Prof Food Technology, NSW Univ Technology, since 1952. Of Sydney; b. Vienna, Austria, 19 Sep 1905.

[2] F. Reuter, "The Preparation of Acaprin", *Australian Chemical Institute Journal and Proceedings*, Vol. 16, p. 164 (1949).

CHAPTER 27

INVENTIONS

AFTER Federation the granting of patents passed from the States to the Federal Government, which exercised its right to do so under the *Commonwealth Patents Act, 1903,* legislation modelled closely on the British patent system.[1] As long as agricultural, pastoral and mining industries continued to dominate the Australian economy the number of patents granted was small, but as soon as secondary industry began to develop, as it did after the first world war, applications for patents increased, both in number and in variety.

In 1907 Australia became a member of the International Convention for the Protection of Industrial Property, thereby gaining privileges of reciprocity in the granting of patents. All countries belonging to this convention had embodied in their legislation provisions whereby an applicant in any one of them could obtain a patent in any other, subject of course to compliance with the domestic laws of each, and could moreover receive the same date for this patent in all countries. The general trend was towards patenting by organisations rather than by individual inventors. Most of the patents (70 to 80 per cent) granted in Australia were taken out by large oversea organisations or their Australian associates or subsidiaries.

Australia was unique among English-speaking countries in arranging the publication of specifications within six months after the application had been lodged.[2] This was so for Australian and foreign applicants alike, with the result that important scientific and technical information, especially from overseas, might become available at the Patent Office in Canberra long before it was published in scientific and technical journals. However the commissioner could, on security grounds, prohibit or restrict publication, a power he exercised widely during 1939-45.

The number of patents granted in Australia (to both local and oversea applicants) from 1939 to 1945 is shown in the accompanying table.

Year	Patents applied for	Patents sealed
1939	5,740	3,141
1940	4,438	2,480
1941	4,060	2,127
1942	3,793	1,795
1943	4,604	1,424
1944	5,860	1,243
1945	7,349	1,248

[1] The granting of a patent took the form of the issue of Letters Patent, a legal document which gave an inventor exclusive rights "to make, use, exercise and vend" this invention for a period of sixteen years.

[2] The *Patents Act, 1903-50* provided for the publication two months after lodgement of the complete specification. The period was lengthened to six months in Section 43 of the *Patents Act, 1952-54.* The usual time overseas was between one and two years.

The low number granted was to some extent due to delays in making applications that normally would have been made in the years 1940-43, and also to delays in processing those that had been applied for. This delay was a consequence of the drastic reductions made in the staff of the Patent Office during the war; it took some time to recover, and delays in processing continued for several years after the war. Practically every major patent office overseas went through the same experience.

A form of reciprocity which existed not only between the members of the International Convention but between patent offices throughout the world, was the interchange of specifications for patents taken out in different countries, irrespective of whether an application had been made to have the subject patented in Australia. Specifications of this kind received in Australia ran into large numbers, as is shown in the accompanying table. Through this practice the Commonwealth Patent Office became the repository of a vast, though not widely appreciated, store of scientific and technical knowledge. It had, for example, a copy of every British specification, from No. 1 granted in 1617.

Reprints of Patent Specifications received during 1938

Country of origin	No. received
Britain	19,314
United States	38,425
Germany	15,608
France	14,000
Italy	11,160
Japan	4,843
Czechoslovakia	3,150
Denmark	1,526
Hungary	1,250
Sweden	3,325
Norway	1,458
Switzerland	7,190

The outbreak of war affected the Patent Office in several ways. Firstly, publication of patent specifications likely to have a military value was held up at the discretion of the Commissioner of Patents. The existence of a state of war did not entitle individuals or firms to operate enemy-owned patents; under the *Patents, Trade Marks, Designs and Copyright (War Powers) Act, 1939,* application must be made to the Attorney-General for a licence to practise enemy-owned patents, subject to the payment of such royalties as the Attorney-General determined. These royalties were held by the Custodian of Enemy Property for the duration of the war. Not many patents were worked under this arrangement.

It was no part of the Patent Office's responsibility to encourage or develop inventions; it examined claims exhaustively to see whether they were novel and met the statutory requirements, and if satisfied on this score the commissioner issued Letters Patent. The granting of Letters Patent was

of course no guarantee that the invention to which they referred was either practicable or useful. The general idea behind the legislation was that once a person had secured a patent he must stand or fall by his own endeavours to exploit it.

The effect of the war on many inventors and would-be inventors was to cause them to turn their attention to ideas and devices that would help the armed services. Often they were interested less in patenting their ideas than in seeing them adopted. Here the Patent Office could be of little help to them. Inventors therefore began to plague members of parliament and army administrators with their ideas, and the press began to criticise the failure of both to assist the adoption of allegedly sound inventions. Ultimately the whole matter of inventions and their development reached a climax over the Owen Gun, whose story has been told in an earlier chapter. How inventors were assisted somewhat belatedly to bring their ideas to fruition is the theme of the present chapter.

From time to time writers have attempted to draw a distinction between invention and scientific discovery and between inventors and scientists, but it is becoming increasingly difficult to do so. There are those who believe that as a general rule scientific discoveries come from a systematic and logical attack by highly-trained people working on specific problems in well-equipped laboratories; that inventions, on the other hand, may be and often are made by relatively untrained individuals working independently and more less intuitively. This view cannot be sustained in the light of modern trends in patents. As mentioned above, the great majority of patents today emanate from well-equipped private or government laboratories or from the drawing boards of large-scale engineering or manufacturing organisations. Furthermore, most of the few patents taken out by individuals involve quite advanced technological knowledge. As far as patents are concerned, then, the individual inventor is a dying species. Probably no other factor contributed to the slowness of wartime attempts to foster inventions so much as the doubt whether individual inventors, especially the untrained ones, had anything useful to offer.

In 1939 the army was the only Service with an organisation for dealing with inventions submitted by the public. This was the Army Inventions Board, with its subordinate the District Inventions Board. Inventions submitted to the navy and to the air force were referred to the Admiralty and the Air Ministry in London. For the relatively few inventions proffered at the time, these arrangements seemed more or less satisfactory, though there was nothing about them calculated to encourage inventions in any really effective manner.

During the first year of the war the number of inventions, for the most part not developed much beyond the new-idea stage, that were submitted to the Army Inventions Board grew so rapidly that it became clear to the Chief of the General Staff (Sir Brudenell White) that something must be done if they were to be adequately examined. On 9th August 1940 he sent the following letter to the Defence Committee:

The number and variety of inventions which are at present being submitted to the Army for examination have quite outgrown the resources of the Army Inventions Board for dealing with them. Although a large percentage of those examined are found to be of little practical value, it is important that action should be taken as quickly as possible to develop such ideas or inventions as may be applicable to Service requirements. I feel that the organisation for dealing with these inventions might now be considered by the Defence Committee with a view to including the requirements of all three Services and also utilising the technical experience of representatives of scientific and industrial bodies.

I have discussed this matter with the Chancellor of the Melbourne University and also with Sir Herbert Gepp and have proposed to incorporate personnel possessing technical knowledge into a suitably organised Inventions Board. I am assured that the assistance we require would be freely given and, in fact, there is a feeling that greater use might be made of scientific knowledge of this nature in regard to Service requirements. . . .

White concluded by setting out the following recommendations for the consideration of the Defence Committee:

(*a*) That a Central Inventions Board should be established to examine and report upon all inventions for Defence purposes.

(*b*) That the present machinery for dealing with inventions at the headquarters of the three Services be absorbed in the Central Board.

(*c*) That the Central Inventions Board should consist of representatives from
  (i) each of the three Services,
  (ii) Supply Department,
  (iii) universities,
  (iv) industrial organisations.

In accepting this recommendation the Defence Committee expressed the view that the Council for Scientific and Industrial Research was the appropriate Commonwealth scientific authority for representation on a central inventions board, and accordingly proposed that such representatives should replace those of universities and industrial organisations. At the same time the Defence Committee conceded that representatives from the latter could be coopted when necessary.

Acting on the Defence Committee's proposals, the War Cabinet established in September 1940 a Central Inventions Board to be responsible to the Department of Defence Coordination.[3]

On the face of it this seemed a sound enough plan, but the Central Inventions Board had not been in operation many months before it was realised that all was not well with inventions. There were still protests to Federal Parliament and the press that the development of useful inventions was being delayed if not actually obstructed. From many prominent scientific bodies and institutions came statements urging a better use of the country's scientific resources.

In the hope of improving this unsatisfactory position a conference was called in May 1941 of representatives of the Central Inventions Board,

[3] The members of the board were: Department of the Navy: Eng Rear-Admiral P. E. McNeil, Director of Naval Engineering, Capt L. A. W. Spooner, Director of Ordnance, Torpedoes and Mines; Department of the Army: Col G. P. W. Meredith; Department of Air: Pilot Officer S. R. Bell; C.S.I.R.: Sir George Julius, Chairman of the CSIR.

the Department of Defence Coordination and the C.S.I.R. to discuss the Acting Prime Minister's proposal that the C.S.I.R. should take over the direction and control of the Central Inventions Board. The representatives of the C.S.I.R., however, made it quite clear that the council did not wish to undertake the secretarial duties of the Central Inventions Board. The most serious revelation of the conference (as far as the prospects of success for the Inventions Board were concerned) was the fact that none of its members felt that there was any real need for the existence of the board. It was also pointed out that the board was responsible to a non-technical department (Defence Coordination) which could not furnish any help of a scientific or technical nature.

Although the board had been established with the purpose of examining and reporting upon all inventions submitted for defence purposes, it did not in fact do so. It still left the sifting of possibly useful inventions to the Services themselves and in so doing lost any chance it might have had of becoming an effective body. Service officers were too busy to give much time to work of this nature.

One of the greatest difficulties in handling inventions lay in winnowing the chaff of thousands of useless and fantastic ideas and proposals from the few grains of worthwhile inventions. Members of the Services were able to devote only a small part of their time to examining inventions, and in any event the large numbers of useless inventions submitted to them tended to make them regard all inventions as a nuisance. There were peculiar psychological, technical and even legal difficulties with which they were quite unable to cope.

It took little short of a threat of an enemy invasion to force Australian authorities into taking some more effective action. On 14th January 1942 the Minister for the Army, Mr Forde, convened a conference of leading scientists, administrators and Service representatives. In his opening address the Minister said:

> Very definitely an Inventions Board is wanted with a character and constitution which will not only tap the worthwhile element in the stream of inventions but will positively and actively encourage and energise Australian inventive genius. The Government will not be content with anything less.
>
> This country may shortly be thrown completely on its own resources. No one knows or is entitled to assume that we will not be faced with shortages of an acute character needing all our inventing and improvising genius to overcome. . . . I do not accept the view that because we have a small army and are a relatively small nation we cannot expect to make any major contribution. I believe the possibility exists. I want it to be explored. For this reason I take the view that the Army should be concerned not only with ideas originated in the first instance by outside individuals, but it should make known its own requirements in order that inventive genius may be directed along channels to produce what is required. . . .

This more positive attitude towards inventions was shared by most of those present at the conference, and in the course of a single afternoon enough constructive criticism was forthcoming to permit the formulation of a much clearer and more effective policy towards inventions than had hitherto been possible. The recommendations of this conference were in

due course laid before the War Cabinet, which on 27th January 1942 made the following decision:

1. That an Army Inventions Directorate[4] be established consisting of the following Directors:
   (*a*) A Chief Executive Officer who is to be nominated by the Directors in session and who will devote the whole of his time to the business of the Directorate;
   (*b*) Six other Directors as recommended by the Department of the Army.
2. That the functions of the Directorate be to receive, develop and adjudicate upon inventions and suggestions forwarded to the Directorate, and to examine problems presented by the Army with a view to ascertaining whether a satisfactory solution can be developed.
3. That the Directorate function directly under the Minister for the Army, have its own full-time technical and clerical staff and have at its disposal such funds as may be authorised by the Minister and provided by the Treasurer.
4. That the Directorate be responsible for setting up the appropriate organisation for dealing with Army inventions in each Military District.

The essential thing was that the new body was to be an autonomous civilian directorate provided with scientfic and technical staff and funds. Army Inventions Directorate was a misnomer, because eventually it went a long way towards achieving what the Central Inventions Board had set out to do—namely, to act for all three Services. With its headquarters in Melbourne the directorate in August 1942 comprised the following members:

L. J. Hartnett (Chairman)
Sir George Julius
Professor Eric Ashby
F Lt S. R. Bell[5] (Inventions Officer, Dept of Air)
R. W. Hill[6]
Brig J. W. A. O'Brien, Director of Artillery
Maj-Gen O. F. Phillips[7] (temporarily representing Army General Staff)
F. R. Sinclair[8] (Secretary, Dept of the Army)
C. S. Teece[9] (Commissioner of Patents)
Air Cmdre E. C. Wackett,[10]
Dr R. v.d.R. Woolley, Chief Executive Officer.

It was not until August 1943 that a navy representative (Lieut-Commander Hutchison[1]) attended a directorate meeting. He was succeeded in

[4] For an account of the Army Inventions Directorate's work I am greatly indebted to "Invention in War—Record of the Origin, Growth and the Achievements of the Army Inventions Directorate in the War Period. March 1942 to September 1945" by A. S. Fitzpatrick.

[5] Sqn Ldr S. R. Bell. (Served 1st AIF.) Staff Officer for Inventions RAAF till 1946. Consulting engineer; of Melbourne; b. South Yarra, Vic, 3 Aug 1898.

[6] R. W. Hill. Representative of Amalgamated Engineering Union in Central Dilution (Engineering Trades) Committee 1942-43; Investigation Officer, Dept of Labour and National Service, 1943-49. B. Glasgow, Scotland, 1 Oct 1900. Died 15 Jan 1949.

[7] Maj-Gen O. F. Phillips, CMG, DSO. (Served 1st AIF.) QMG and 3rd Member Military Board 1934-39; Inspector of Coast and AA Defences 1939-42. Regular soldier; b. Warwick, Qld, 9 Jun 1882.

[8] F. R. Sinclair, CBE. Secretary, Dept of Army, 1941-55. Of Melbourne; b. Nurrabiel, Vic, 6 Dec 1892.

[9] C. S. Teece. Deputy Commissioner of Patents to 1940, Commissioner 1940-50. Of Canberra; b. Sydney, 6 Mar 1885.

[10] AVM E. C. Wackett, CB, CBE. Air Member for Engineering and Maintenance 1942-48, for Tech Services since 1948. Of Melbourne; b. Townsville, Qld, 13 Aug 1901.

[1] Lt-Cdr R. B. C. Hutchison, RN. I/c Torpedo School RAN 1940-43. B. Edinburgh, 13 Mar 1908.

March 1944 by Captain L. A. W. Spooner. During the life of the directorate there were changes and additions to its members.[2]

Since, so far as was known, no similar body had been developed by other Allied Nations, there were no guiding precedents for its organisation. At the outset the staff was grouped under five divisions, each representing some phase of the handling of an invention: submission, requirements, examination, development and commercial divisions. Branch offices headed by a manager who acted as submissions officer for that area were established in Sydney, Adelaide, Brisbane, Perth, Hobart and Newcastle. In the early part of its life there were still a few doubters on the directorate who believed that little or nothing of real technical value could originate in the minds of untrained inventors. To these members the directorate at first seemed over-staffed, but as the months wore on it became quite clear that there was always more work to be done than the staff could handle. When the directorate got really under way its members wholeheartedly supported applications for increased staff and technical facilities.

There were a number of fairly well defined stages through which an invention had to pass before it was adopted in practice. The organisation of the activities of the directorate was centred on these stages. The first was submission: the inventor either put his invention on paper in descriptions illustrated with diagrams, or explained his ideas by word of mouth to a submissions officer, whose duty it was to receive and record the invention. This officer had a most important task calling for technical knowledge, tact and enthusiasm. His job was not to pass judgment on the merit, soundness or desirability of the invention, but merely to see that it had been clearly stated. Many inventors lacked the ability to express themselves clearly and concisely, and the submissions officer had to make sure just what the inventor intended. Inventions were classified on lines based on the "Manufacturers and Word Index" used in the Patent Office in Canberra, a system that worked so well that it was possible to turn up any one of the 21,000 inventions dealt with by the Army Inventions Directorate within a few minutes.

The next stage was to make a critical examination of the ideas submitted, a task handed over to appropriate scientists or engineers. Often in the course of assessing the value of new ideas the directorate turned to universities, technical colleges, learned societies and government departments for help. To the examiners fell the highly responsible task of seeing that no good inventions were rejected and that useless ones were not backed. They had first to decide whether an invention was feasible and technically sound—that it did not run counter to established physical laws. Secondly they had to determine whether the invention was novel and if so whether it offered any real improvement over what was already known.

[2] At various times the following served as members: S. H. Hampson (Amalgamated Engineering Union), Col C. C. F. Spry, Prof Kerr Grant, Prof T. H. Laby, Col H. G. Edgar, Brig J. K. Coffey, Cdr N. K. Calder, Col C. W. Tyrrell, Lt-Col F. E. Kiel, Dr A. S. Fitzpatrick (appointed Chief Executive Officer in 1945).

Every invention was examined by at least two technical officers and by the military consultant. If they were unanimous that the invention lacked merit or usefulness, a tactful letter was sent to the inventor, explaining, if considerations of security permitted, the reason why. Occasionally better alternative devices were available but it was not always deemed safe for reasons of military security to tell the inventor what they were. The work of the examiners ended with acceptance or rejection of an invention, and if accepted its reference to a possible user.

Other questions that had to be answered were: Was the improvement embodied in the invention sufficient to warrant its adoption in view of interference with present practice in production; and did the invention require the use of materials in short supply?

In referring an invention to possible users, the intention was to discover whether it was likely to be of any use to the Services or to government departments. Towards the end of the war these questions were investigated by the Reference Committee,[3] which either rejected the invention or passed it on to the directorate for formulation and development, depending on the replies received from potential users. An important channel for the views of users was the Army New Munitions Committee, consisting of high-ranking military officers who were concerned with the operational value of the ideas and inventions rather than their technical details. Formulation meant collecting information on such matters as cost, time for production, most suitable place for manufacture, and other related details. If the directorate was satisfied that the prospects were favourable, it sanctioned the development of the invention. This decision might, as it sometimes did, involve the directorate in expenditure running into thousands of pounds. Development consisted of building a model or prototype, an undertaking carried out either in the directorate's workshop with its inadequate drafting and design facilities, or in whatever place it could best be done.[4] Although capable of producing original ideas, many inventors lacked the training and specialised knowledge needed to bring them to fruition. They often lacked the qualities of mind required to work with a developmental team. There were, of course, outstanding exceptions, but as a general rule unless an inventor had a sound basic technical training he was not permitted to be too closely associated with the developmental stage.

To make sure the invention was a really sound one, the model or prototype was thoroughly tested, first by the directorate and then by the possible user. Once it had been accepted the invention passed out of the

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[3] Consisting of the Chief Executive Officer, Secretary, Military Consultant, Chief Examiner, Development Engineer and Officer in Charge of Submissions.

[4] The directorate received important help in this phase of its activities from the Universities of Sydney, Melbourne, Adelaide, and Tasmania; Commonwealth Solar Observatory; Munitions Supply Laboratories; Mineral Resources Survey; C.S.I.R.; State Electricity Commission of Victoria; Research Laboratories of the P.M.G. Dept; Dept of Civil Aviation; C'wealth Small Arms Factory; R.A.N. Torpedo Factory; Diecasters Ltd (Melb); Slazengers Aust Pty Ltd (Sydney); Communication Engineering Pty Ltd (Sydney); Muller Pty Ltd (Sydney), to mention some of the more important only. Help of a more general nature was received from the Scientific Liaison Bureau and the Army New Munitions Committee.

directorate's hands, the user being given the responsibility of making the production drawings and arranging for the actual manufacture.

Inventions dealt with by the directorate fell, broadly speaking, into two classes: those whose usefulness was likely to be confined to the armed forces, and those whose usefulness might be expected to extend to the community at large after the war. The latter class was complicated by the need to protect the inventor's rights; in the course of the directorate's inquiries to establish the value of an invention, the disclosure of certain details might jeopardise the inventor's claim to protection under the *Patents Act*. In January 1943 the relevant National Security Regulations were modified to enable the directorate to make investigations without impairing inventors' rights. Where an inventor had not sufficient money to patent an invention of the second group, the directorate gave him financial assistance, though not without some kind of agreement under which he might be required to repay the Commonwealth the whole or portion of the expenditure incurred by the directorate in the development of an invention with post-war commercial possibilities. Inventors whose ideas were adopted by the Services but not patented received *ex gratia* payments after the war.

Where an inventor was on active service he was often not in a position to make application for Letters Patent to protect his invention. In these circumstances the directorate would arrange for one of its members, a qualified patent attorney, to draft the application.

The directorate was responsible not only for developing inventions submitted to it, but also for actively encouraging invention by members of both the armed forces and the civil population. Some care had to be taken on the way this was done. Too direct and too general an appeal to the public, especially after some setback in the progress of the war, was found to result in a flood of useless inventions and ideas which seriously wasted the time and energy of the directorate.[5] A more successful method of approach was to place advertisements in trade, technical and professional journals. Advertisements indicating problems to be solved and inventions needed were not very successful; most of the best inventions that came in were the result of independent and original discovery of the problem or need.

Thousands of posters were prepared and distributed to the army, universities, technical colleges and munitions factories. Lectures were given and films shown to workers in munitions factories. Ministerial statements and special articles in the press drawing attention to the work of the directorate all helped to keep the need for inventions before the public.

Another device adopted by the directorate was to make grants of up to £50 to inventors who had submitted meritorious ideas that were for one reason or another not adopted, with the hope of stimulating their energy to produce further ideas. It was made clear that these grants did not entitle the inventor to receive royalties or an *ex gratia* reward.

[5] There were exceptions. In May 1945 the directorate drew attention through the medium of the daily press to the need for mechanical means to clear the sand from thousands of miles of stock and domestic water channels in Victoria and parts of New South Wales. The public response was excellent, some 400 suggestions (including useful ones) resulting.

The kinds of invention submitted were to some extent determined by the events of the day. When the directorate was first set up in March 1942 the minds of most inventors were preoccupied with the requirements of the forces in the Middle East, and more particularly of the requirements of desert warfare: the need for better armour, mine detectors and gun-flash eliminators. Later, when the New Guinea and island campaigns were at their height, the requirements of jungle warfare received much attention. In the last phase of the war, when food production became a matter of great urgency, many devices designed to increase efficiency in this activity were received.

As an illustration of the wide range of ideas put forward by inventors, the following has been drawn up to show the projects upon which the directorate authorised expenditure in 1942:

Title of Project	Name of inventor	Expenditure £
Delayed action A.T. shell	J. Pomeroy	97
Flash indicators	F. Stevenson	67
Blast and flash eliminators	F. Stevenson	40
Rocket research	E. R. S. Faulkner	40
Predictor	M. W. Sterling	249
Splinter locator	A. Miller	193
Vehicle water still	A.I.D.	162
Constant recoil gun	R. S. Robinson	5,947
Bomb fuse against A.F.V.	W. B. Topp	13
Flame thrower	State Electricity Commission	411
Compensating silencer S.M. Gun	W. Hatfield	27
Percussion grenade development	L. R. Gleadall	480
Grenade	G. P. Rhoades	—
Pyrophylite	Mills and Kearns	—
Whistle cartridge	A.I.D.	8
Front fork spring for motor cycle	E. Copleton	11
Mine locator	A. Miller	181
Guard flaps for tyres	J. M. Main	1
Combined H.E. and incendiary bomb	L. R. Gleadall	25
(Polarised light) signalling	C. L. O. Streeton	—
Portable hydrogen generator	A.I.D.	146
Air lift propulsion	Wild and Wolnizer	500
Optical glass surfacing machine	R. P. Hepworth	125
Bullet-proof radiator	P. S. Barna	1,494
Photostat copying device	Sgt A. R. Payten	633
Underwater acoustics	Barnes and Yelland	22
Body armour	R. Welch	480
Machine-gun new type	W. C. Gatenby	472
Cast iron milling cutter	A. Rooks	42
Cross bow gun	J. Wright	82
Aircraft navigation device	J. N. Stephenson	—
Combined R.F. and gun sight	W. L. Hallam	—
Mechanical robot	H. E. Jeffrey	186
Electro-micrometer	E. T. Both	132

Many inventions were of course adopted without the need for further development, and this list does not, therefore, exhaust the inventions received by the directorate during 1942. Throughout the course of its work the directorate examined 21,645 submissions, of which 3,686 were referred for acceptance and expert advice. Of the latter 175 devices were built and tested. The number finally accepted for development was 127, or 0.58 per cent of the total submitted. Though this may appear to be a very small yield, it compares favourably with results obtained in countries overseas. A few only of the more important inventions will be described to illustrate lines along which inventors worked.

Two important lifesaving devices were adopted. The first of these was a float raft for ships. Before the war such rafts were made of South American balsa wood to ensure maximum buoyancy. This unusually light wood was no longer available and some substitute was needed. A Sydney furniture manufacture, Mr Mills,[6] proposed a design for a cellular raft made of plywood. Plywood made with a water-resistant adhesive was used to build a structure of about 26 cells which could be left empty or filled with kapok as required. In either case the buoyancy of the raft was due mainly to the air in the cells. Destruction of a few of the cells did not greatly impair its efficiency. As designed it was capable of supporting ten men and would continue to do so even if half the cells were destroyed. This raft, of which more than 2,000 were made, was adapted for naval vessels and for small water craft used by the army. Even after they had been considerably damaged by shell fire during action in the Philippines, cellular rafts from H.M.A.S. *Australia* were still quite effective.

The other lifesaving device was a signalling mirror to enable airmen or sailors adrift on rafts to signal their presence to searching aircraft. One day while reading how the survivors on a raft from a torpedoed freighter were saved by flashing sunlight from an empty tobacco tin, a soldier of the first world war, Tom Robertson, who recalled how he had seen warships off Gallipoli heliographing code messages, determined to improve on the tobacco tin. Even if a survivor on a raft possessed a mirror, he was still faced with the problem of reflecting a beam of sunlight directly at the searching aircraft, for it was only then that the aircraft could readily become aware of the mirror. It was easy enough to play a beam of reflected light on a specified spot on a wall, for example, but without some special device it was not possible to see whether a reflected beam was striking a distant object. What Robertson did was to use the well-known laws governing the reflection of light to make a sighting device that would catch the sun's rays and automatically reflect them on to the searching aircraft when it appeared in the sight. Robertson's device was not the first of its kind, but it compared more than favourably with those developed overseas, and was therefore adopted. Some 20,000 were made and distributed. No record exists to give any indication of the probable number of lives saved by its use. After the

[6] F. Mills. Furniture designer and draughtsman with E. Mills and Sons since 1929. Of Sydney; b. Sydney, 8 Mar 1909.

war it was used by the Flying Doctor Service in Australia to indicate to a pilot the best landing spot for an aircraft approaching to pick up a patient from a locality where no prepared airfield existed.

Among the inventions intended to meet service requirements in the Middle East was a robot tankette submitted by Corporal Jeffrey[7] of the R.A.A.F. This project was inherited by the directorate from its predecessor. The tankette was a small, caterpillar-tracked vehicle about 4 feet long, 2 feet wide and 18 inches high, weighing about 4 hundredweight and having a space of 3½ cubic feet to carry explosive. Small battery-operated motors propelled the vehicle and steering was achieved by the help of trailing cables connected to the two motors. It could be used to detonate mines by remote control, and could also be sent to blow up small bridges. Although tests on the tankette were successful, the army did not consider the need for such a device was great enough to justify using the materials and manpower to put it into production. The fact that similar robot tanks developed in Britain and in Germany had proved relatively ineffective was also taken into account, and the tankette was never adopted.

While watching an official film of fighting in the Western Desert in April 1941, Mr A. Miller was impressed with the need for a better method of searching for land mines than merely prodding the earth with bayonets as was done by Australian soldiers. Miller, who had had experience in locating metal objects in abandoned gold mines in Western Australia, immediately set about working out a suitable detector. The result was an instrument having two wireless valves, the first of which operated as an oscillator, coupled to a tuning coil which formed a searching loop carried at the end of a light rod; the other valve acted as a regeneration receiver. When correctly tuned, any change in the loop capacity inductance (such as was caused by the presence of a metallic object or a mine) would cause an audible note in the earphones of the operator.

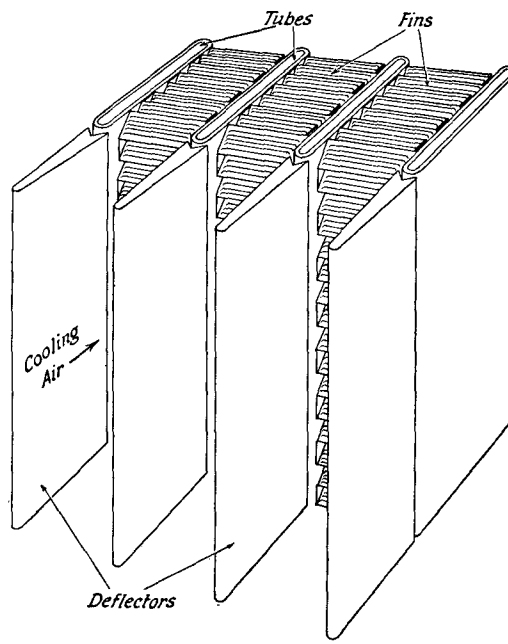
Unfortunately this invention was first submitted before army inventions had been placed on a satisfactory basis, and much delay occurred in its development. When it was finally taken up by the directorate, in June 1942, Miller was given financial assistance to construct a model which was submitted for army tests. These tests, carried out at East Oakleigh (Victoria) in the presence of representatives of the Engineer-in-Chief, proved so successful that within a fortnight the device was declared by the Army New Munitions Committee to be an army requirement. Many months later the invention was incorporated in service equipment under the name of "Detectors Mine No. 1 Aust". Like many inventions it was destined to be replaced by something better, but before this had happened it gave much valuable service.

During the North African campaigns the extreme vulnerability of motor vehicles to damage by bullets was a problem. If the radiator, for example, was put out of action the whole vehicle was immobilised. A young

[7] Corporal H. E. Jeffrey. (Served 1st AIF.) Attached to Inventions Directorate 1940-42; Cpl RAAF 1942-45. Sheep farmer and motor engineer; of Wee Waa, NSW; b. Wee Waa, 18 Feb 1897.

Hungarian engineer, Mr Barna,[8] then in the Australian forces, put forward a suggestion for making the radiator less susceptible to bullet damage. The directorate was sufficiently impressed with Barna's proposals to obtain leave for him to return to Australia. On his return he consulted Professor Stephens, of the Department of Aeronautics in the University of Sydney. Between them they designed a greatly improved radiator which was built and put to the test in May 1943. Subjected to rifle and machine-gun fire from a distance of 40 yards, the radiator remained undamaged. Such damage as was suffered by the louvred fins did not seriously impair the function of the radiator itself.

Conventional methods of bullet proofing then in use in Service vehicles provided for armoured shutters which could be closed when necessary. The obvious disadvantage of this arrangement was that when closed insufficient air could pass through to allow the radiator to function as it should. Barna overcame the difficulty by placing a series of vertical, bullet-deflecting, armour plates edgewise in front of the water-carrying tubes of his radiator. These tubes were elongated flat tubes formed from thin armour plate, and connected, for heat dissipation, by very light-gauge louvred fins or plates of copper. The short fins gave a considerably greater heat transfer per unit area of surface than the relatively long continuous fins of the conventional radiator.



BULLETPROOF RADIATOR STRUCTURE

This invention met a fate shared by many made in time of war in that it came up against economic factors. Developmental work was slow, as is generally the case, and by the time the device was perfected so many thousands of vehicles had been fitted with the ordinary type of radiator that it was not considered profitable to introduce a new one.

One of the most promising inventions brought to the directorate was the application of the constant reaction principle by a young officer, Flight Lieutenant Robinson,[9] of the R.A.A.F. Robinson, a dynamic and

[8] P. S. Barna, ME. Research and development engineer with Ganz and Co, Budapest, Hungary; then with Waugh and Josephson Ltd, Sydney; served in AMF 1942-44. Lecturer, Univ of Sydney, to 1948. Of Budapest; b. Hungary, 4 Apr 1912.

[9] F Lt R. S. Robinson, BSc. Area Tech Officer RAAF 1941-42. Aeronautical engineer; of Melbourne; b. Hamilton, NZ, 11 Jun 1911.

colourful personality whose early wanderings had taken him to the Antarctic with the Byrd Expedition and later to the Massachusetts Institute of Technology in the United States where he had done a course of aeronautical engineering, returned to Australia early in the war with the intention of making wooden aircraft. It was while working on the design of such an aircraft that he was faced with the problem of devising a method of mounting guns in the wings so that the destructive effect of their recoil when firing could be avoided. Robinson's solution was a "recoil-less" gun. The gun was so designed that, immediately before firing, the breech block barrel and reloading elements were brought back against a powerful spring. When the trigger was pressed the whole mechanism was projected forward and just before reaching the limit of its run out, the shot itself was fired. Matters were so arranged that the momentum of the forward-moving mass was about one half of the momentum of recoil, so that the breech block and reloading elements could be returned to their initial position ready for the next shot. In this way a near balance was obtained between the momentum of the moving masses actuated by the spring and the momentum of recoil.

Robinson submitted his invention soon after the formation of the directorate, and while waiting for a decision set about making a model to demonstrate the principle. By efficient scrounging he managed to gather enough parts to adapt a 0.5-inch standard Browning machine-gun so that it could be fired from the shoulder. Armed with this he gave a demonstration before Air Force and United States authorities but failed to gain support for his ideas. One of his later demonstrations, made before an audience that included an American serviceman, aroused the latter's competitive instinct. If Robinson could fire his gun from the shoulder so could the American fire an ordinary Browning in the same manner. In the attempt he suffered so severely from the recoil that he had to be taken to hospital.

After thoroughly investigating Robinson's claims the directorate decided to give strong financial support to his invention, classing it as a major project, and in January 1943 an order was placed for the design of a 0.5-inch calibre gun to a preliminary specification furnished by the Department of Air. The long delay that occurred in bringing the invention to this stage has been explained as being due to the difficulties of obtaining the necessary facilities in Australian workshops and of obtaining a team of experts in gun design. There were very few of such men in Australia at the time. A second model was completed in May 1943 by Slazengers (Australia) Pty Ltd. Trials on it showed that although much more developmental work was essential the invention warranted further attention, and it was decided to transfer the project to Melbourne where better facilities existed in the workshops of Diecasters Ltd. Here efforts were concentrated on bringing a 0.5-inch calibre aircraft gun (known as S.R. Model 5) to a stage where an exact instrumental test could be made of Robinson's claims. Hitherto the tests had been purely qualitative and subjective in character, depending on the individual's judgment of the effect

of firing the gun. The Lubricants and Bearings Section of the C.S.I.R. was, however, able to design an instrument for measuring the extent of the reaction from a model. Tests fully substantiated Robinson's claims. They showed that his device reduced the effect of the recoil from an automatic weapon on its mounting to about one seventh of the normal value. Moreover, the force on the mounting during the firing of the gun was a constant one.

At this stage demonstrations given before British, American, Canadian and Australian Service representatives called forth the highest praise, and matters began to move more rapidly. The Admiralty, War Office and Ministries of Supply and of Aircraft Production in England became so interested that early in 1945 Robinson was asked to go to England for consultation. He left Australia on 27th January 1945 and on arrival in England was attached to the staff of the Chief Engineer Armament Design. In a very short time the British authorities had twelve of the S.R. Model 14 guns (the re-designed version of the S.R. Model 5) manufactured and tested. Meanwhile in Australia developmental work was in progress at the Lithgow Small Arms Factory. The war ended before the invention could be regarded as having been completely developed. After the war interest in it was sustained, but even at time of writing not all the inherent difficulties had been overcome. One of the chief remaining problems was said to be that of finding more suitable materials for withstanding the unusually heavy strains put upon them.

Another brilliant Australian invention was made by Mr Sterling,[1] who as early as November 1938 drew the attention of the Australian Government to certain ideas he had about synchronising and controlling anti-aircraft guns. Unfortunately he knew little mathematics and was not a draughtsman.

In March 1942 Sterling approached the Minister for the Navy, who referred him to the directorate. He was brought to Melbourne, where officers of the directorate thoroughly examined his proposals. In the course of these examinations his ideas underwent modification in details but the underlying principles survived. With the cooperation of the Engineering Department in the University of Melbourne a model was built embodying Sterling's principles. About this time it came to be appreciated that, although Sterling had put forward his ideas in 1938 and had apparently no knowledge of the many predictors that had been developed throughout the world, he had in fact hit on the principle of the well-known Sperry predictor. Whether Sterling had in fact anticipated Sperry was never established. Although this invention came to nothing, it demonstrates that highly original technical ideas can occasionally be produced by an ingenious layman. It was his misfortune that the organisation that might have helped him was set up too late to bring his ideas to fruition in time for them to be of use in the war.

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[1] M. W. Sterling. Mechanical engineer. Of Adelaide; b. South Shields, Eng, 19 May 1901.

Another ingenious invention that came to nothing during the war was Mr Both's[2] apparatus for transmitting line diagrams over telephone lines or by radio. This equipment survived extensive army field trials and tests only to come up against similar facsimile equipment developed overseas. It was with great reluctance that the directorate abandoned this project.

In forcing the Japanese back over the Kokoda Trail in 1942 the Australian forces moved through such rough country that the only way of getting supplies forward quickly was to drop them from the air. "Free dropping" presented considerable problems: the fall damaged ammunition and foodstuffs, which were by no means plentiful, and a high proportion of bundles fell into rivers or dense jungle and were lost. Silk or even calico parachutes to break the fall were so scarce that a substitute, either smaller in size or made of cheaper material, was urgently needed. Mr Griffiths[3] of the Ordnance Production Directorate, who was deputed to take up the problem with the Inventions Directorate, evolved a device consisting of a heavy-gauge wire-netting cylinder known as the "aeropak". The cylinder had provision for a parachute bucket at one end and at the other end a tail for streamlining, the wire mesh being intended to collapse and so absorb shock on landing.

The "aeropak" was improved on at the firm of Morris and Walker Pty Ltd of Melbourne, which developed the "storpedo", consisting of a cylindrical cardboard body with a parachute bucket at the top and at the base a conical nose.[4] With a "storpedo" 14 inches in diameter and 3 feet long, a load of 250 pounds was safely dropped with a hessian parachute about half the size customarily used. This device was adopted and many thousands were used both by the Australian and the American forces. Long after the war it was used in dropping supplies to the victims of several devastating floods in New South Wales.

The inventions so far described were sufficient to justify the directorate's existence. It will now be interesting to mention four relatively minor inventions which actually saved money—indeed the amounts they saved almost covered the £140,000 that it cost to run the directorate during the war.

As a means of camouflaging army and air force posts in New Guinea, vast quantities of wire netting were required. The netting was garnished by gluing irregularly shaped bits of coloured low-grade wool, a task that was both time-consuming and tedious. Having had much experience of the tedium, Sapper R. S. Boyle was spurred on to produce a machine to do the work. A sum of £300 was provided by the Department of Home Security (which was then responsible for camouflage) for developing the machine. The Victorian State Electricity Commission and the State Defence Camouflage Committee also gave valuable help. As soon as the Army

[2] E. T. Both, OBE. Inventor and scientific instrument maker of Both Equipment Ltd. Of Adelaide; b. Caltowie, SA, 26 Apr 1908.

[3] G. W. W. Griffiths. Engineer, Aircraft Dept Scottish Motor Traction Co, Edinburgh, 1938-41; personal assistant to Director of Ordnance Production 1941-44. B. Sydney, 1 Sep 1902.

[4] The invention was patented in the names of E. R. Campbell, K. M. Frewin, F. W. Lennox and R. P. Morris.

New Munitions Committee declared the machine to be an army requirement, the directorate gave further financial support. With the help of the directorate's technical officers and experts from the Victorian State Electricity Commission, improvements were made to Boyle's machine and several were built. By this time Australian forces were attacking rather than defending posts, and the need for camouflage netting was rapidly diminishing. In the short time during which the machines operated it was estimated that a saving of approximately £27,000 had been effected by their use.

Mr Pearson's[5] service ration calculator, which was in effect a kind of ready reckoner, enabled a quarter of the number of clerks to do the same number of calculations and with greater accuracy. On the basis of the army order for twenty machines Fitzpatrick[6] estimated that there would be an annual saving of £16,400.

A channel-clearing machine designed with the help of the directorate but not built until after the directorate had ceased to function, was estimated as being likely to save £50,000 annually in the clearing of sand from stock and domestic water irrigation channels. Development of this machine was ultimately taken over by the State Rivers and Water Supply Commission of Victoria.

Another invention handled in the latter part of the directorate's existence when the trend was towards devices to help in agriculture, was a flax-turning machine invented by Mr Schroeder[7] to eliminate the need for the tiring and slow hand-turning of the windrows of flax. An annual saving of £22,000 was the estimate made of the effect of adopting this invention.

The well-known zipp fastener had a number of shortcomings in so far as it readily became clogged and put out of action by entry of foreign matter which prevented the engagement of its knobs and cavities. Its flexibility was more or less restricted to movements in two dimensions. These disadvantages were overcome by the Goldner brothers, musicians by training, who reached Australia from Vienna just before the war. They evolved a fastener which they called the "Triflex", consisting of two coils of wire, each of equal pitch and diameter but of opposite winding sense. Locking was achieved automatically by a displacement of opposite members of the fastener, and since it was not dependent upon the engagement of knobs and cavities or of hooks and loops, it provided flexibility in all directions. The device was patented both in Australia and overseas.[8]

Tests and consideration of the invention by the Services were prolonged, and it was not until fairly late in the war that it was adopted by the Services

[5] G. Pearson. Wholesale grocery representative; department and store manager in NZ and Aust. Of Brisbane; b. Feilding, NZ, 7 Jul 1910.

[6] A. S. Fitzpatrick, MSc, PhD. Scientific Liaison Offr, in England, for CSIR 1925-35; Chief Exec Offr, Army Inventions Directorate, 1945; Chairman, War Inventions Award Cttee, since 1951. Of Melbourne; b. Heyfield, Vic, 18 Jun 1901.

[7] J. S. Schroeder. Motor mechanic. Of Winchelsea, Vic; b. Winchelsea, 4 Jan 1917.

[8] Although the Goldner brothers obtained and successfully exploited patents in the zipp fastener field the basic principle they adopted appears to have been the subject of an earlier (1925) patent, No. 22198/25.

for joining marquees and tarpaulins, and for other purposes. It was also taken up by the American army and air force.

These were only some of the contributions that came within the purview of the Army Inventions Directorate.[9] Many others, some of them equally meritorious, must perforce be passed over.

At the end of the war when the directorate was disbanded, opinions on how useful it had been varied considerably even among those who had been fairly closely associated with it. At one extreme were those who thought of it mainly in negative terms: as a device for preventing the thousands of would-be inventors from harassing politicians and army officers. It will be recalled that of 21,645 ideas submitted only 127 were developed. Though it was an important function of the directorate to divert this stream towards itself, to credit it with no more than this is to do it less than justice. It is true that the directorate produced no battle-winning devices, but this was hardly surprising. Some scientists with inventive ability preferred to look after their own inventions and in this they may well have been wise. The directorate cast its net far wider and did most to assist inventors least able to develop their own inventions. It began its work two years or more after war began and did not possess all the technical facilities, such as drawing offices and teams of designing draughtsmen, necessary for the efficient discharge of its responsibilities. Nevertheless on balance it must be credited with many valuable contributions to the prosecution of the war. Its success encouraged many inventors and scientists to hope that the Government would, as part of its post-war reconstruction policy, constitute a similar body to develop peacetime inventions. The Government of the day was apparently not impressed by the arguments put forward and nothing was done about it. Some years later, when the United Kingdom set up the National Research Development Corporation to secure the development and exploitation of inventions, attempts were made to do something similar in Australia, but with no better success than had attended the earlier efforts.

The Commonwealth did not, however, neglect its obligations to inventors of the war years who had not been adequately rewarded at the time they made their inventions. In 1953 a War Inventions Award Committee was set up to advise the Attorney-General on claims for awards. The committee was told that it should not only do justice but also give the appearance of doing justice. Awards of as much as £1,000 and £1,500 were made in the course of carrying out this instruction.

[9] Others were: S/Sgt F. J. Marett's use of steel wire mesh (A.R.C.) for packaging; W. L. Hallam's combined range finder and sight; W-O A. C. Rae's gauge for adjusting timing of distribution; R. Welch's body armour; F. A. Stevenson's flash simulator and flash eliminator; A. R. Sharp's atomic hydrogen searchlight; F. R. Sly's potato digger; R. W. Newton's post-hole digger; M. J. Baron's maize harvester.

CHAPTER 28

OPERATIONAL RESEARCH

AMONG the many new applications of science in the war of 1939-45 few had a more far-reaching influence on tactics than operational research. For the first time in history,[1] and at the instigation mainly of Professor Blackett,[2] the methods of scientific research were applied on a large scale to the study of the performance of new types of equipment and to the operations of war. There was no universally accepted definition for operational research, but one that met with fairly general acceptance was that put forward by Kittell, who described it as

> a scientific method of providing executive departments with a quantitative basis for decisions regarding operations under their control.[3]

In order to understand how the Australian Army and Air Force came to adopt operational research, and to appreciate the nature of its impact on their activities, it will be helpful to view these events against the background of the early history and achievements of operational research in the United Kingdom.

The story, as told by Sir Charles Goodeve, of its early close association with the Royal Air Force, not only reveals something of the nature and scope of operational research but also gives a hint why, when it came to be adopted in Australia, it should have exercised a greater influence on the air force than on either the army or the navy.

> Operational research was really born out of the Battle of Britain. As is well known, we had in 1940 few fighter aircraft compared with the number that would have been required to defend our shores against an air invader. We had very good fighter pilots and very good aircraft, but, with the equipment and methods used prior to 1940 it would have been impossible to obtain sufficient interceptions to defend our shores. The most important new feature that came in was, of course, radar. This equipment by giving ample warning, permitted the retention of aircraft on the ground until needed and then by plotting the positions of the enemy and defending aircraft, enabled a "ground control" to direct the aircraft to a position where the enemy could be sighted visually. The planning of this sequence of operations involved careful analysis of training and operational experiences and involved a full analysis of the technical possibilities of the equipment. But the process of combining these factors required mathematical calculations beyond the experience of the ordinary commanding officer. Accordingly a small party of half a dozen scientists was attached to Fighter Command to study and refine the deployment and the operational orders. These scientists learned to estimate which were the bad targets and which were the good, and to determine where and how our limited effort could best be expended. Their analyses formed the basis for the operation of the whole defence organisation of Britain. It is estimated that radar itself increased the possibility of interception by a factor of about ten; but that, in addition, this small operational research team increased the probability

[1] Operational research was foreshadowed by F. W. Lanchester in *Aircraft in Warfare, the Dawn of the Fourth Arm* (1916).

[2] P. M. S. Blackett, FRS, MA, DSc. (Served RN in first world war.) Prof of Physics, Univ of Manchester, 1937-53, Imperial Coll of Science and Tech, London, since 1953. B. 18 Nov 1897.

[3] C. Kittell, *Science*, Vol. 151 (1947), p. 2719.

by a further factor of two, which together meant that the Air Force was made twenty times more powerful. The operational research contribution, a doubling, was out of all proportion to the amount of effort spent on the research.[4]

It would have been surprising indeed if knowledge of so rewarding an application of science had not spread to other members of the British Commonwealth and to the United States. Fortunately there was sufficiently close liaison between these countries and frequent interchange of scientists to permit the rapid diffusion of techniques such as operational research.

Two operational research groups were set up within the Australian Army, independently of one another and about the same time. While the initiating steps appear to have been taken more or less simultaneously, the first to begin work was the group sponsored by the Major-General Royal Artillery, Major-General J. S. Whitelaw. Attached, supposedly temporarily, to the M.G.R.A. Branch, the Army Operational Research Group under the leadership of Dr D. F. Martyn began its activities on 1st June 1942. The subsequent activities and influence of this group were, like those of the second group, determined to a large extent by their place in the military organisation.

It was essential for the success of an operational research team that it should be composed of men with a natural bent for such work and led by a scientist of really high calibre. In Britain, where the first valuable results came from the application of operational research to tactics and strategy, scientists worked in close contact with top executives and were in the confidence of commanders. They attended conferences at which orders were given, and had access to intelligence reports. Having no executive responsibilities the scientists were free to examine and analyse military operations dispassionately and critically, much as they were in the habit of examining problems in the laboratory.

Martyn had urged that his group should be attached to MacArthur's Headquarters so that it could function at the highest tactical and strategic level, but since the Americans had scientists of their own interested in work of this kind, nothing ever came of this suggestion. When, as will be described later, the second army operational research group was formed, some definition of their respective fields of work became essential. The result was that Martyn's group was restricted to weapon research in general and to radar in particular. This in itself was not necessarily a bad thing, and is mentioned here simply to explain the restricted nature of the program undertaken by the group, much of which could hardly be regarded as falling within the compass of operational research.

The new and complex technical equipment then coming into use by the army offered plenty of scope for weapon research. If, under the generally favourable circumstances that exist in a laboratory, it takes considerable time to get complex scientific equipment working efficiently, as it often does, it can be appreciated that in the field of battle, where the unexpected is always happening, radar equipment, for instance, would require

[4] Sir Charles Goodeve, "Operations Research", *Nature*, Vol. 161 (1948), p. 377.

even more study. The presence of scientists in Darwin during February 1942, when Australian radar was first used against the enemy, made all the difference between success and failure in the use of the equipment.

By recruiting science graduates with honours in physics and mathematics, the Army Operational Research Group was gradually enlarged to fourteen members, most of whom retained their civilian status.[5] There seem to be several schools of thought about the necessity of this; those urging the wisdom of retaining civilian status do so in the belief that only in this way can the scientist talk freely to military commanders and chiefs of staff. Those maintaining the contrary view hold that close collaboration between commanders and scientists is not necessarily jeopardised by putting the scientist into uniform.

Martyn made no attempt to recruit men with engineering experience since the group was not to be concerned with design and maintenance but with the scientific principles involved in the efficient operational use of radar equipment. It was to concentrate on those irregularities in performance of new equipment which were outside the control of the design and maintenance staff. Members of the group who were posted to operational areas advised local commanders on the best tactical use of radar equipment and the best method of using information obtained from it. Operational scientists gave special attention to its general effectiveness rather than to its technical efficiency and freedom from breakdown, and also to the problem of eliminating interference between various types of radar equipment and communication services. In New Guinea, for example, it was found that English G.L. Mark II equipment caused serious interference with radio communication services up to a radius of about half a mile, a problem which apparently did not arise in England, where different communication techniques were employed. The Operational Research Group found the nature of the interference and developed a satisfactory remedy for it.

Had equipment remained static in principle and design it is reasonable to assume that the work of this group would have been completed in a relatively short time. As it was, there were changes not only in the equipment used by the Australian Army but also in that used by the enemy, with the result that there was a steady supply of problems. Among the most interesting were those caused by the phenomenon known as superrefraction.[6]

Spurious echoes often giving rise to false alarms were observed at almost every radar station in Australia. Once the origin of these anomalous echoes was understood it was possible to train operators to recognise them and thus avoid giving false alarms. These echoes were eventually traced to an abnormality in the propagation of radio waves which was caused

[5] Some members of the group who later visited operational areas did so in uniform. There they made contact with actual operational problems affecting all three Services.

[6] Whether this work on superrefraction can be called operational research is hardly a matter of debate. Most authorities would agree that it is not. The fact is that the vagaries of radar equipment arising from this cause formed the subject of much investigation by Martyn's group. Some reference, it is felt, should be made to this work if only to show what happens to an operational research group when it is not related to military commands as it should be.

by superrefraction. In a homogeneous medium, radio waves, like light, travel in perfectly straight lines, but on passing from one medium to another both radio and light waves undergo a bending, or refraction. Since, under normal conditions, the lower layers of the atmosphere are physically and optically denser than the upper layers, radio waves undergo a slight bending towards the earth, but nothing like enough to cause them to follow the earth's curvature for any appreciable distance.

Because it is optically much denser than dry air, water vapour in the atmosphere greatly influences the behaviour of radio waves. The presence of unusually large amounts of water vapour in the lower parts of the earth's atmosphere causes a correspondingly large refraction or bending of radio waves. This is known as superrefraction. It so interested Martyn that towards the end of the war its study became one of the main preoccupations of his group.

Superrefraction did not always produce spurious echoes; sometimes echoes were absent under conditions when they were expected. Theoretical considerations showed that when there were marked discontinuities in the humidity gradient of the atmosphere, high-frequency radio waves could be refracted in such a way as to produce "blind" zones in which a high-flying aircraft might be undetectable.[7] It was difficult to prove the existence of such blind zones with certainty since there were many other reasons, including the human factor, why aircraft should remain undetected in apparently favourable circumstances. The existence of blind zones was the probable explanation of the disappearance from radar view of the Japanese reconnaissance aircraft that flew over Sydney on the night of 4th April 1943. A Hudson which was searching for the aircraft was also intermittently lost to radar view.

While the diminution in range of a radar set for detecting *high-flying* aircraft owing to refraction effects could not at that time be so readily demonstrated, the extraordinary increase of range on low-lying objects arising from the same phenomenon was well established. Many abnormal echoes observed on radar screens were caused by reflection from objects such as hills or islands normally below the radar horizon, while a set whose normal range for the detection of a ship was only 20 miles, might suddenly be able to detect ships at a distance of 200 miles.

Superrefraction arises over sea or land when a mass of relatively cool and damp air underlies warm dry air, a condition which often occurs on the coast of north-west Australia.[8] Here the dry hot wind from the desert blows out over the sea and only the lowest layer becomes moist and cooled. The phenomenon is so strongly developed off Darwin that several times a month air warning sets (1.5 metres) operating there reported echoes from the coast of Timor, 300 to 500 miles away. Users of similar equipment near Broome, Western Australia, observed echoes from the coast of Java, 900 to 1,100 miles away. In February 1944 a high-flying Catalina was followed almost continually for a distance of

[7] This phenomenon finds a parallel in the total internal reflection of light.
[8] F. J. Kerr and J. K. Strachan, Radiophysics Laboratory Report RP 259/1, Aug 1945.

800 miles on its journey from Perth to Colombo by the air warning station at Geraldton.

A useful contribution to the knowledge of superrefraction was made by the R.A.A.F. and army stations round the coast of Australia and New Guinea when, following the suggestion of the operational research scientists, they made daily observations on the phenomenon as part of their regular duty. As with some of the data of meteorology, such widespread regular observations could hardly have been made in peace time owing to the prohibitive cost of maintaining so many stations at isolated points. The observations and their interpretation by radiophysicists were duly published and in this way became a useful by-product of wartime activities.[9]

The second army operational research group originated from an offer made by the War Office in London to the Chief of the Australian General Staff (General Northcott[1]) to send out a team of experts who had undergone special courses of instruction with the British Army Operational Research Group. Having obtained the approval of General Blamey, Northcott gratefully accepted the offer. The team, which reached Australia in July 1943, comprised Lieut-Colonel P. A. E. Jump, R.A., Major J. L. McCowen, R.E.M.E., and Captain G. G. Vickers, R.E.M.E. Northcott was advised that each member had specialised in a different field of military activity and that the best results would most likely be obtained by using them as a team.

The team's duties, as set out in an early memorandum, revealed a bias towards weapon study. They were (i) to collect factual and scientific data on the performance and tactical handling of equipment under operational conditions; (ii) to collate these data in order to provide scientifically based evidence to assist in the guidance of General Staff policy; (iii) to investigate the suitability of new equipment and tactics under development; (iv) to explore the need for new or modified types of equipment and to suggest basic specifications for such equipment.[2] Operational research had, of course, much wider application to military affairs than this list might suggest: it was applicable to problems of organisation, maintenance and training and to tactical studies in general. It was originally intended that the team should be attached to the General Staff, but after some top-level discussions it was finally placed within the Branch of the Master-General

[9] F. J. Kerr, "Radio Super-refraction in the Coastal Regions of Australia", *Aust Journal of Scientific Research*, Series A, Vol. 1 (1948), p. 433.

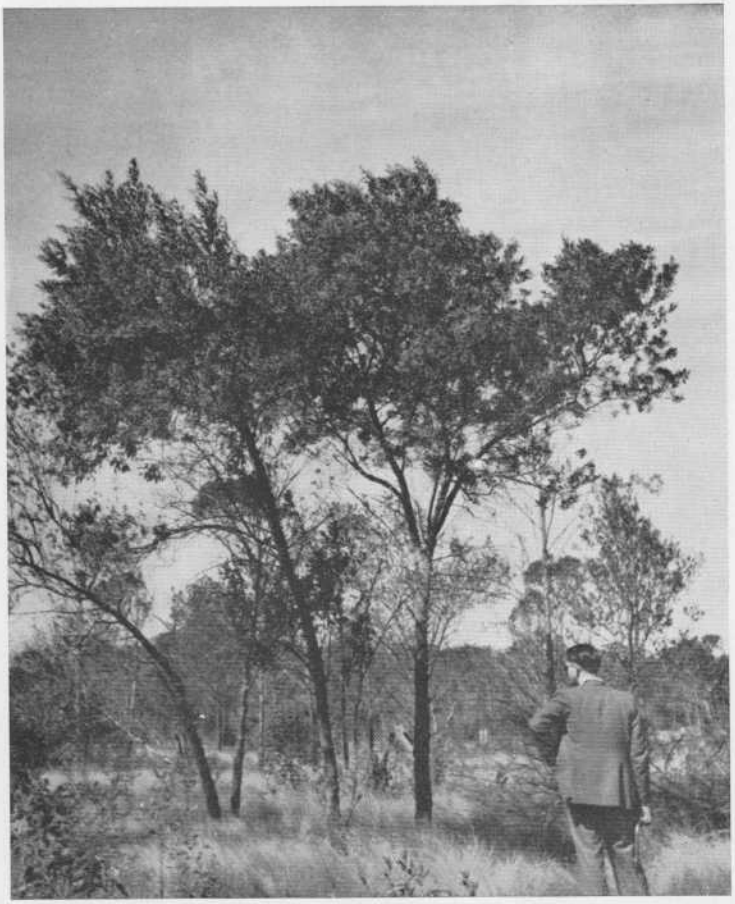
[1] Lt-Gen Sir John Northcott, KCMG, KCVO, CB. (Served 1st AIF.) GOC 1 Armd Div 1941-42; CGS AMF 1942-45; C-in-C BCOF Japan 1945-46. Governor of NSW since 1946. Regular soldier; b. Creswick, Vic, 24 Mar 1890.

[2] "The primary function of an operational research section is to obtain factual evidence in forward areas on both tactical and technical value of weapons and equipment. This evidence is obtained by:
(i) the collection and critical analysis of facts and quantitative data of military problems as opportunity offers and by critical appreciation of the effectiveness of new or modified weapons before or after they reach the user;
(ii) scientific assistance in the planning and reporting of trials and experiments carried out locally and in the solution of immediate problems, such as countering new enemy weapons or technique;
(iii) collection and critical analysis of eye-witness reports and opinions from both our own troops and prisoners of war."
From Appendix "B4" from the *Administration of the MGO Branch of the Staff, LHQ, and of the MGO Services 1944-* , Vol. 1.



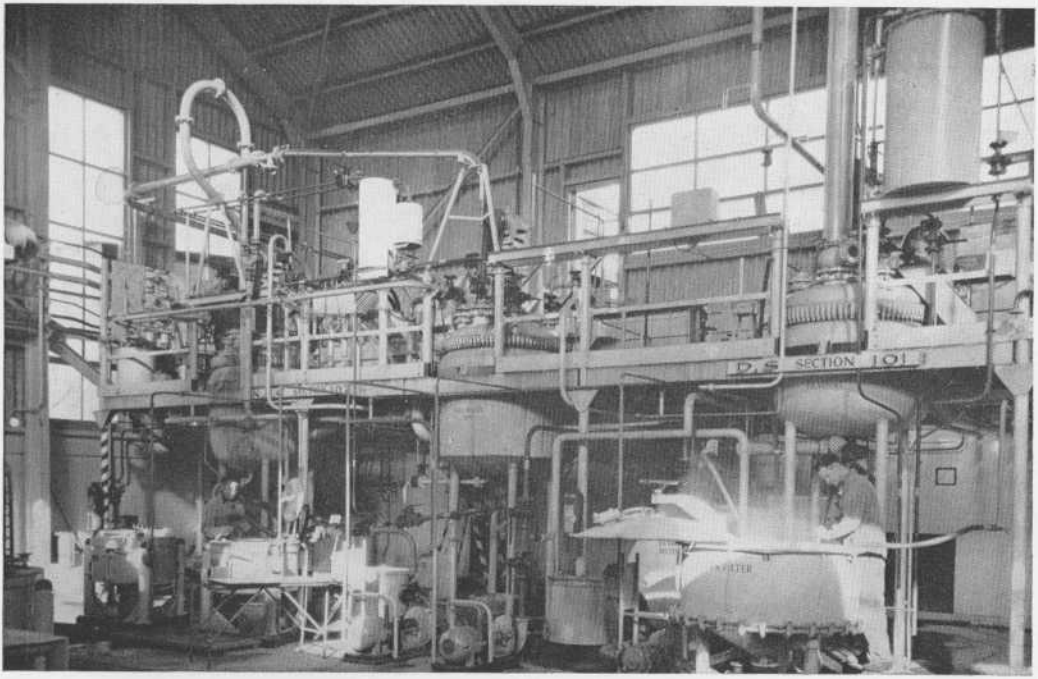
(*Division of Plant Industry*)

Leaf and flower of *Duboisia Leichhardtii*.



(*Division of Plant Industry*)

Duboisia Leichhardtii at Monogorilby, Queensland.



Sulphamerazine Plant. (*I.C.I.A.N.Z.*)



Executive Committee of Army Inventions Directorate, May 1945. Left to right: E. C. Allen, Dr R. v.d.R. Woolley, Cdr N. K. Calder, Sqn Ldr S. R. Bell, Dr A. S. Fitzpatrick, Brig J. W. A. O'Brien, L. J. Hartnett.

of the Ordnance, a disposition which almost certainly influenced the direction of the team's activities.

Overseas, operational research whether at the tactical and strategical level or at the level of weapon study, appears to have been most successful when applied to repetitive operations such as submarine hunting, convoying and bombing raids. If one may judge from the relevant reports and memoranda, the campaigns in the jungles and mountains of New Guinea offered little scope for operational research.

The following are only a few of the subjects studied, but they will serve to illustrate what the section and operational commanders who initiated investigations understood to be legitimate subjects for operational research. Much of the work done would, in the opinion of many operational research scientists, more properly belong to a testing establishment, since it consisted of what were primarily developmental trials.

At the beginning of August 1943 Jump and his colleagues went on to the forward areas in New Guinea, where they began a series of investigations, one of the first of which was a study of factors affecting the operational life of dry batteries.[3] The Scientific Mission which had visited New Guinea some months earlier had already looked into this question and had urged that manufacturing specifications for dry batteries should be altered to suit tropical conditions. Captain Vickers, who took up the study of this problem, found that in some instances batteries more than twelve months old were being issued to the troops in ignorance of the fact that storage for such a period, even under the best conditions in a temperate climate, would have greatly reduced their useful life. Manufacturers then knew very little about the effect on the shelf life of a battery of the high humidities combined with the high temperatures experienced in the tropics, though they were aware that shelf life was much shorter in tropical than in colder climates. While careful packing in sealed metal containers did much to ensure that batteries arrived in good condition up to the point of issue, the main difficulty was often experienced after this time: batteries of small portable wireless sets and mine detectors were often exposed to the most severe conditions, including complete immersion in water. Only after the operational researchers' recommendation that batteries should, when not in actual use, be carried in completely waterproof bags, was trouble from this source alleviated.

In due course the Operational Research Section was enlarged to include Australian officers with research and army experience. After it had been in the field about twelve months the original team of three British officers was replaced by another team from the United Kingdom, thus ensuring that the latest experience and techniques were available to the Australian section.

The Japanese, realising that they were unable to establish a continuous system of defence in long stretches of coastline in northern New Guinea,

[3] Operational Research Section Memo No. 18, "Factors Affecting the Operational Life of Dry Batteries in New Guinea" (1943).

concentrated their defences on beaches most obviously suited to landing operations. The outcome of this policy was that they left undefended a number of beaches that were naturally protected by a narrow knife-edge reef of coral running parallel to their length, in the belief that such beaches were impregnable. Except for this barrier many of these beaches were eminently suited to a landing operation. They were open to assault by shallow-draft vessels at high tide but were not accessible to major landing craft laden with vehicles and stores. The Operational Research Section undertook to investigate methods of breeching coral reefs in order to open up the possibilities of a tactical surprise.[4] After trying out several methods the team decided that experiments should be made with naval depth charges, but when application was made for help in securing the necessary charges, it was learned from the Naval Board that "the landing of assault troops on a beach being a naval responsibility, the removal of any obstruction in the water also becomes a naval responsibility". Thereafter the interest of the Operational Research Section in this project lapsed.

The problem of locating survivors of aircraft that had crashed in jungle and mountainous country was one that caused much concern in New Guinea. Its investigation became the joint responsibility of the Australian Jungle Training (Survival and Rescue) Unit and the Operational Research Section. So many aircraft were lost without trace that little was known about the geographic distribution of crashes, their preponderance, if any, at certain altitudes, on hillsides, or the frequency with which searching aircraft passed within range of survivors. Little or nothing was known of the proportion of survivors whose injuries would not have prevented them from using some signalling device, or of the number of occasions on which survivors had any idea of where they had come down.

In the face of these difficulties little headway was made with the problem. After critically examining ten methods of search, the Operational Research Section recommended that each should be given a trial, but could offer no suggestion which was most likely to succeed.[5] It is doubtful whether, in the circumstances, much more could have been done in the limited time given to the problem.

Nothing was known of the effect of firing small arms through kunai and other tall grasses that grow in profusion in New Guinea and other parts of the South-West Pacific Area. Trials to discover the effect of tall grasses

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[4] P. A. E. Jump, Notes on "The Breeching of Coral Reefs for the Passage of Major Landing Craft", ORS Memo No. 23.

[5] Major C. Powell and Capt J. A. Thornton, "The Location of Survivors of Crashed Aircraft in Jungle and Mountainous Country", Memorandum No. 34. The methods suggested were:
1. Radio transmission (SCR.536 handy talky, 5 miles' normal range).
2. Homing beacon for radio compass.
3. Radar homing beacon.
4. Radar air/sea rescue beacon.
5. I.F.F. (radar).
6. Radar reflector on captive balloon.
7. Captive balloon as visual marker.
8. Area marker for use at night (Krypton flashes visible at 20 miles).
9. Carrier pigeons. (These were successfully used in air/sea rescue in England.) Range in New Guinea 60-70 miles.
10. Robertson sun-flash signalling device.

All except (5) would have to be operated by a survivor, and carried down in the course of bailing out.

on the range and changes in angle of elevation of a bullet's trajectory were made in the Markham Valley (New Guinea). The differences in the performance of Bren, Vickers and Owen guns when fired through grass under various conditions were carefully analysed.[6]

In tests made on the Atherton Tablelands during the months of June, July and August 1944, a comparison was made of the accuracy for range of the 25-pounder Mark II and the Australian short modification of the same gun.[7] As was expected the short gun possessed neither the range nor the accuracy of the Mark II, but it was considered sufficient for the purposes for which it was intended.

Army interest in operational research lapsed at the end of the war and was not revived until 1952 when Mr Blunden was appointed Chief Scientific Adviser to the Army. In 1953 Blunden visited London to investigate the best way of setting up a scientific organisation within the Australian Army. His principal conclusion was that operational research should form the basis of scientific advice at the executive level, and on the strength of this he set about building up an appropriate organisation. It is interesting to note that among the first subjects chosen for investigation were the Wiles steam cooker and the Owen gun.

In Australia the R.A.A.F. appears to have taken operational research more seriously than the army and to have tackled it along broader and sounder lines, giving it a more appropriate position within its organisation.[8] As against this, the R.A.A.F. was slower in adopting it. From 1942 onwards scientists in the C.S.I.R. and the universities had attempted to interest the air force in operational research, but a firm decision to undertake it was not made until late in 1943.[9] This decision was reached after conversations between Sir Henry Tizard (then Scientific Adviser to the Air Council of Great Britain) and Air Commodore McCauley[1] (Deputy Chief of Air Staff, R.A.A.F.), in which Tizard strongly urged the Australian air force authorities to make more use of their technological and scientific resources.

Steps were immediately taken to bring together a team of suitably experienced research workers—no easy task since at this late period of the war most scientists had already gone into other Service and civilian organisations. Squadron Leader Davis,[2] a highly competent young mathematician of Sydney University, began some preliminary administrative work at Air Force Headquarters, Melbourne. In the meantime the British Air Ministry, at the request of the Australian Air Board, arranged to lend

[6] Lt-Col H. Dickson, Memo No. 33: "The Effect of Small Arms in Tall Grass".

[7] Memo No. 45, ORS (Aust), "Range Accuracy of the Quick-firing 25-pdr Mark II and of the 25-pdr (short) Mark I Aust".

[8] I am indebted to W Cdr J. C. Bower and Sqn Ldr A. D. Thomas for helpful discussion in connection with this section.

[9] The introduction of operational research into the RAAF was promulgated in Air Force Confidential Order A4, 18 Jan 1944.

[1] Air Marshal Sir John McCauley, KBE, CB. Dep Chief of Air Staff RAAF 1942-44, 1946-47; Air Cmdre Ops 2 TAF, European Theatre, 1944-45; Chief of Staff BCOF, Japan, 1947-49; Chief of Air Staff RAAF 1954-57. B. Sydney, 18 Mar 1899.

[2] W Cdr C. S. Davis, DFC; MSc, PhD. RAF 1940-42; RAAF 1942-46; Professor of Mathematics, Univ of Q'land, since 1956. Of Strathfield, NSW; b. 15 Apr 1916.

the services of two Australian scientists (Dr Bower[3] and Dr Miller[4]) who had been working as operational research officers in the R.A.F., Middle East and South-East Asia Air Force Commands. While on their way to Australia these officers visited air force operational research organisations in Canada and the United States. Bower, with a strong background of scientific training and of experience in the R.A.F., became the leader of the new organisation. Miller took charge of the section at R.A.A.F. Command, and Davis was appointed to the section in New Guinea. Later, when the war moved from New Guinea up into the islands, a section was started in the First Tactical Air Force area under Squadron Leader Loveday.[5]

These different sections were always part of the Air Staff. Operational research section leaders were themselves directly responsible at R.A.A.F. Headquarters to the Chief of the Air Staff, and at commands to the Air Officer Commanding. They had no executive responsibility and so were free to devote their energies to research.

Since different scientific disciplines were likely to be called upon in operational reseach, well-balanced teams included men with different backgrounds—physicists, chemists, mathematicians, biologists and psychologists. The R.A.A.F. teams built up by 1945 were well organised in this respect. A natural consequence of the fact that operational research grew out of the first attempts to study the military efficiency of radar was that the first teams were made up mainly of physicists and mathematicians. As the scope of operational research widened, it became necessary to recruit men whose training lay in fields other than the exact sciences. Thus biologists were often found particularly effective in collecting the personal stories needed in tactical studies; in investigating the efficiency of personnel it was logical to employ psychologists.

Not until early in 1945 was an adequate staff recruited and trained. In the meantime the different sectional leaders did the best they could with the staffs at their disposal and succeeded in obtaining some interesting results in widely differing spheres of activity.

As the R.A.A.F. authorities conceived it, operational research covered not only combat operations but any operation within the Service. Research activities fell into three main groups:

(*a*) those directed towards providing assistance in the formulation of future operational requirements in the planning, strategy and tactics of operations and improving the combat efficiency of the air force;

(*b*) those directed towards helping administrators achieve maximum working efficiency of the air force: how best to distribute resources of manpower, equipment, buildings and aircraft in order to achieve the objectives of the service;

(*c*) those directed towards problems relating to personnel: health and efficiency, selection, training methods, training assessment and morale.

[3] W Cdr J. C. Bower, MSc, PhD. O i/c Operational Research Section, RAF HQ, Middle East, 1942-43, RAAF 1944-45. Of Heidelberg, Vic; b. Melbourne, 3 Oct 1911.

[4] Sqn Ldr A. R. Miller, MA, MSc, PhD; RAFVR. Research physicist; of Cambridge, Eng; b. 4 Sep 1915.

[5] Sqn Ldr N. J. Loveday, MA; RAAF. Company director; of Brisbane; b. Rosewood, Q'land, 5 Dec 1914.

Researches which had the most profound effect on the efficiency of waging war came mostly under (*a*). Examples illustrative of each of these groups will be given to indicate the range of interest and the extent to which the R.A.A.F. made use of operational research.

Commanders were supplied with a factual analysis of operations under their control. An example of this was an analysis made of the amount of flying and the resulting casualties in three types of aircraft: the Kittyhawk, Boomerang and Spitfire.[6] Kittyhawks, usually employed in low-level strafing on bombing attacks against Japanese ground installations and small ships, paradoxically suffered more casualties in the forward areas when engaged in non-operational flights—that is, flights other than those against the enemy—than when flying on combat missions. The number both of flying hours and of sorties was taken as the basis for comparison. Casualties were in fact more closely related to the number of sorties made than to the actual time of flying. The reason for this was that for all types of single-engined aircraft a high proportion of casualties was sustained in the vicinity of the target area owing to enemy anti-aircraft fire and fighter aircraft, and at the base during landing and take-off. In other words, there were small periods of time for which an aircraft was exposed to risk, which were independent of the number of hours occupied in flying to and from the target area. Another point of some interest which emerged from statistical analysis was that Japanese anti-aircraft fire was more than twice as dangerous as their fighter aircraft.

For the purpose of estimating the rate at which aircraft should be supplied to keep pace with losses, an investigation was undertaken by the section with the cooperation of other sections at Air Force Headquarters, in particular the Records Section of the Directorate of Organisation. It was established that the incidence of non-operational casualties, reckoned on the basis of hours flown, was markedly less in rear than in forward areas; that the proportion of casualties experienced in operational and non-operational flights varied with the kind of aircraft; that of the different kinds of operational flying in New Guinea none was more hazardous than tactical reconnaissance—aircraft so engaged suffered a higher proportion of casualties than occurred with any other single-engined R.A.A.F. fighter aircraft in any other role or in any other part of the South-West Pacific Area. When these findings had been collated it was possible to estimate the rate at which aircraft should be replaced.

Perhaps the most important piece of operational research was that carried out by Miller on the sea-mining operations directed against harbours of Japanese-occupied islands to the north of Australia by Squadrons 11, 20 and 43 of the R.A.A.F. during the period April 1943 to April 1944.[7]

The South-West Pacific Area offered few targets of the kind which, from European experience, could be regarded as conventional objects for attack by an air force. Throughout the war in the Pacific and South-East

[6] ORS Report No. AR8, "Effort and Casualties in RAAF Squadrons Equipped with Single-engined Aircraft".

[7] A. R. Miller, "Mine-laying Operations of the RAAF, 22 April 1943 to 30 April 1944", Reports Nos. BR.2 and BR.8, OR Section HQ RAAF Comd, Allied Air Forces, SWPA.

Asia there were no large industrial cities, no chemical engineering plants, no networks of railways and marshalling yards, no large-scale engineering works such as bridges and viaducts which could be destroyed from the air with telling effect on the enemy's ability to wage war. In Western Europe the most crippling of all attacks were those directed against communications networks upon which depended production of the weapons and equipment of war and their supply to the fighting forces.

Despite the great differences between the two theatres of war, one principle of warfare underlying the use of air power was just as valid for the Pacific region as it was for Western Europe. Stated briefly, it was to disrupt the enemy's communications by direct attack and by isolating him from supplies of fuel. The different tactics used to achieve this aim were dictated by the totally different terrain—a land mass in the European theatre, and in the Pacific a vast expanse of sea studded with islands. The task of the R.A.A.F. was to prevent the Japanese from using the sea lanes of the Pacific. This it did by cooping up their ships in the harbours.

Quantitative studies of sea-mining operations were directed to answering two main questions: what proportion of the total activities of the three squadrons was devoted to mining, and what precisely were the results of the operations. The answer to the first question was found to be that irrespective of whether activity was measured by the number of sorties or by flying hours, the proportion devoted to sea mining was roughly 20 per cent of the total, as is shown in the accompanying table.

Duty	Per cent of the total no. of Sorties	Flying hours
Minelaying	20.5	20.8
Bombing	17.6	18.2
General reconnaissance . .	16.4	18.3
Convoy escort	41.4	38.6
Miscellaneous	4.1	4.1

Distribution of effort—Squadrons Nos. 11, 20 and 43.

The answer to the second question was convincing and conclusive: 230 sorties against 18 harbours had resulted in the closing of 10 harbours for periods up to 5 weeks, the sinking of about 60,000 tons of shipping, and the damaging of about 75,000 tons. It was estimated that if the cargoes of these sunken ships had been dispersed among airfields and dumps, their destruction would have required something like 12,000 sorties from 20 squadrons. Since these results were achieved with what was equivalent to half a squadron occupied full time, it meant that minelaying was forty times as effective as the bombing of land targets. Moreover, this estimate took no account of enemy losses due to damaged shipping, to the diversion of effort to minesweeping, and to the loss of war production resulting from dislocation of sea communications. When these indirect effects were taken into account sea-mining operations appeared to have been about 100 times as destructive to the enemy as an equal number of bombing missions against land targets would have been. Not only was sea-

mining a highly effective method of harassing the enemy, it was also one that achieved results with relatively small loss to the attacking force, as the accompanying table will show.

Form of attack	Period	No. of sorties per missing aircraft	Aircraft lost per ship sunk	Aircraft lost per ship sunk or seriously damaged
Low level 600 ft	Mar 1941 Jun 1942	6.2	2.65	1.23
Medium level 4,000 ft	Jul 1942 Mar 1943	25	3.33	2.0
Torpedo	Mar 1941 Aug 1943	5.0	3.65	1.73
Minelaying (Europe)	Jan 1943 Jun 1943	28	1.0	0.85
Minelaying (RAAF, SWPA)	Apr 1943 Apr 1944	77	0.23	0.13

Comparison of different methods of attack on sea communications.

This illuminating analysis had its share in causing the R.A.A.F. to concentrate a much larger part of its effort on minelaying. The immediate result of these mining operations was that Japanese ships were often blown up when entering or leaving a harbour. Consequently the Japanese would then close the harbour in question for days or even weeks while the approaches to it were swept for mines. This immobilised all shipping in the harbour and all that was due to arrive there during the time spent on sweeping operations. The shipping available to the enemy was thereby substantially reduced, and the replenishment of stores and weapons was delayed.

Fewer aircraft were lost for each ship sunk or seriously damaged on these minelaying operations than on any other operation, and the results achieved were out of all proportion to the effort in manpower and materials put into them.

At R.A.A.F. Headquarters operational research men concentrated on problems of administration. One of the first of such problems put up to them by Air Commodore McCauley was that of finding the most efficient way of providing relief for personnel after a reasonable tour of duty in the tropics.

While the importance of giving air crews periodic rests from active flying was fully recognised, McCauley was convinced that it was equally necessary, especially in the tropics, to give periodical relief to ground staff, and in order to conserve manpower he was naturally anxious that this should be done in the most efficient manner possible. Not every man in the rear areas was available for relieving those in forward areas; some were disqualified by age, a key position, or unfitness for service in tropical

areas.[8] The problem was to discover how best to apportion the time to be spent in travel to and from the forward areas and the period of the tour of duty. In answer the Operational Research Section provided a simple formula by means of which the Personnel Branch was readily able to implement a policy of relieving ground staff in the most efficient manner.

The accompanying table, worked out from the formula, illustrates the interplay of the three most significant factors—(*a*) tour of duty in forward areas, (*b*) tour of duty in rear areas, and (*c*) time of transit—affecting the size of the forces which could be maintained in forward areas.

Factors affecting the availability of personnel in forward areas

	Tour of duty in forward areas	Tour of duty in rear areas	Time of transit	Maximum percentage of establishment in North
a	24 months	12 months	14 days	57
b	15 „	12 „	14 „	45.5
c	12 „	12 „	14 „	40.0
d	15 „	6 „	14 „	61.0
e	15 „	1 „	14 „	86
f	15 „	12 „	1 month	44
g	15 „	12 „	3 „	39.5

Obviously the length of the tour of duty in the rear areas had to be kept low if the forward strength was to be kept high. On the other hand, when only a moderate strength was required forward, tours of duty in forward and rear areas could be made of comparable duration. The fact that the time of transit was not a particularly sensitive factor (compare lines *b*, *f* and *g* of the table) did not mean that it could be left out of account; for example, under the extreme conditions stated in line *g* of the table, 15 per cent of personnel were in transit, which was far too high.

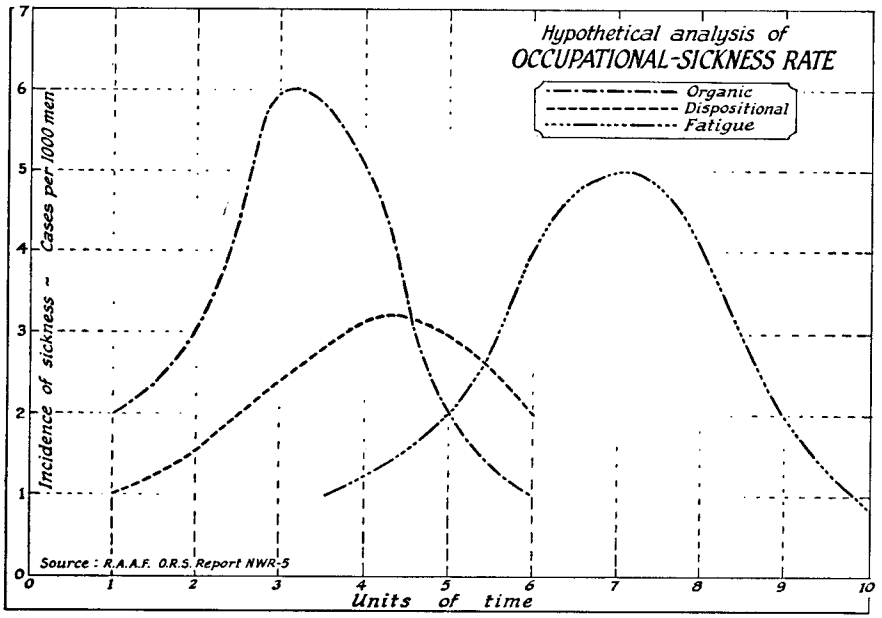
The formula was applied in detail (with appropriate modifications where necessary) to determine possible relative tours of duty in forward and rear areas for each of the 100 or so trades in the R.A.A.F. It is worth noting that this study had a lasting influence on posting policy in the R.A.A.F.; it survived the 1939-45 war and was used in the Korean war.

In another attempt to help administrative officers make the most efficient use of limited supplies of manpower, operational researchers analysed medical statistics to discover the nature and incidence of the different kinds of occupational sickness.[9] Any disorder arising directly from working conditions, whether organic or psychological, was classified as occupational sickness. Organic disorders were those affecting the parts of the body involved in a particular task, and included eyestrain, conjunctivitis, otitis and haemorrhoids. Psychological disorders were divided into two groups: (*a*) dispositional—those constitutionally predisposing states which resulted in conversion hysteria or anxiety states; (*b*) fatigue—neuropsychic dis-

[8] ORS RAAF Report No. AR.2, "Planned Relief". These men totalled 9,900, made up of: unfit, 2,550; under age, 3,050; over age, 1,150; compassionate posting, 650; men in key positions, 2,500.

[9] ORS RAAF Report NWR.5, "Notes on the Analysis of Occupational Sickness".

orders such as headaches, general debility and insomnia, caused by working too long at the one task. The incidence of each of these types of occupational sickness in any large group of people was found to vary in a characteristic way: the number suffering from organic complaints reached a maximum first; then followed dispositional and fatigue disorders. The accompanying figure shows an idealised form of the curves for each type.



A high proportion of dispositional sickness was considered to indicate a need for revising methods of selection at recruitment. The time that elapsed before fatigue disorders reached a maximum was suggested as indicating the length of the period beyond which a person should not be kept on the one job. If kept beyond this period the chances of a rapid recovery were seriously reduced. Recommendations were based on the individual curves because very little could be deduced from the complete occupational sickness curve. The administrative staff was left to formulate its policies in the light of the statistical analyses.

Another study of administrative interest was one relating to the nature and causes of operational inefficiency in signals workers. Extreme examples taken from statistical records showed that it was possible, under the worst conditions, for a teleprinter to make as many as 200 to 250 errors a day, of which 85 per cent might be serious; that under similar conditions cypher assistants could make as many as 120 errors a day.[1] When it is remembered that operators were selected on the grounds of their apparent

[1] The situation was not quite so bad as these figures might suggest. They included typographical errors in text or heading, altering the sense of the word or text; incorrect abbreviation of names of units in addresses; incorrect procedure in setting out the signal. Also it is to be noted that 50 per cent of the serious errors were picked up and corrected by the operator.

fitness for the job, the need for investigating the causes of inefficiency of this degree is clearly apparent. The usefulness of the most nearly perfect signalling equipment could be seriously offset by failure of the human element.

The staff of the Melbourne wireless telegraphy station at Camberwell was chosen as the subject of study because its numbers were large enough to give statistically significant results. In the beginning operational research officers attempted to discover the extent of the variations in efficiency and the principal factors responsible for them. Errors were least numerous during the evening shift (4 o'clock to 11.15), while about equal numbers occurred during the other two shifts (11.15 to 7.30 a.m. and 7.30 to 4 p.m.). As far as could be judged, efficiency increased with pressure of work. There was no sign that operators were extended to the limit of their capacity. Operators working on the same shift for a six-day week were least efficient on the second and fifth days. From this it was concluded that it did not much matter whether a two-day or six-day shift system was used. Male operators working under similar conditions were not significantly more efficient than female operators.

Fatigue, which to the operational research worker meant reduction in efficiency as a result of occupational or temperamental unsuitability, was compounded of two factors: boredom and occupational debility.[2] Boredom was caused by lack of interest-value in the work itself, or by too little work. Its cure lay partly in the provision of proper rest pauses, the value of which had been recognised many years before. The causes of occupational debility were traced to unsatisfactory shift systems, poor working conditions, incorrect "social" treatment of workers, and too long a tour of duty. All these conditions, once diagnosed, could be remedied.

Conditions met with among the signals workers were typical of many routine, repetitive jobs, and the conclusions drawn from these statistical studies were considered to have a fairly wide application in the R.A.A.F.

One of the last wartime studies undertaken by the headquarters group of the Operational Research Section concerned the problems of demobilisation. A critical examination of the "point system", a method then in use for deciding the order in which men were to be discharged, revealed a number of weaknesses, the chief of which was that it took no heed of the labour market. The operational research team divided all servicemen into five occupational groups:

1. Those whose jobs were being kept for them or who through their own endeavour had been able to find jobs or had decided to start a business of their own.
2. Those with qualifications required by essential industries, and for whom there was an immediate demand.
3. Those who wished to resume interrupted training or who had been chosen to begin training at universities and technical colleges.
4. Those with the qualifications for group 2 but for whom positions could not immediately be found.
5. The remainder, for whom no positions were immediately vacant.

[2] The term "debility" was used to cover any type of health disorder which could be closely associated with the work of the operator.

A census was taken of 45,170 persons from Western Australia, Queensland and Victoria, and a group of 32,000 was selected at random to discover how they were distributed among the five groups. Group 5, comprising about 50 per cent, constituted the "labour pool" upon which operational researchers urged that the machinery for rehabilitation, vocational guidance and other benefits for ex-servicemen should be focused. This report did in fact provide valuable guidance for the administrative sections of the R.A.A.F., and was acted upon. Most of the results of this kind of operational research seemed just plain commonsense—in fact this branch of science has been called quantitative commonsense. One basis on which to judge the probable value of operational research is the definiteness of the recommendations made as a result of it; in this respect much of the work done by the R.A.A.F. compared favourably with that done overseas.

It is important to emphasise that operational research scientists were always available for day-to-day advice, and senior officers did in fact frequently use them most effectively as scientific advisers. The advantage to an officer planning some specific operation of being able to rely on substantiated facts rather than on opinion or prejudice, needs no emphasis. The role of scientific adviser steadily became a more important function of the operational research worker as the war proceeded.

Frequently data accumulated by operational research workers provided the basis for Service training or educational manuals. Among the most valuable of these manuals was one prepared by the Operational Research Section of the R.A.A.F., describing the principles of radar, the performance of typical radar equipments, and their operational efficiency. In other ways, for example by making their services available as lecturers, operational research officers assisted in the training of servicemen.

There can be no doubt that operational research influenced wartime policy of the R.A.A.F. to a sufficient degree—at a late stage in the war at least—to justify its existence. It is equally certain, however, that had the section been established earlier and recruited to its full strength in 1943 the value of its efforts would have been much greater. Through the work of Bower, Miller, Davis and Loveday, operational research won the good opinion of many air force administrators. Interest in operational research, though at a reduced level of activity, was sustained after the war and results obtained earlier were applied to the fighting in Korea in the early fifties. The R.A.A.F. had learned to appreciate the contribution that the scientist could make to its general activities. Concrete evidence of this was provided by the appointment of Squadron Leader Thomas[3] as scientific adviser on operational research to the Chief of Air Staff—the first appointment of its kind in the Australian armed Services.

In Britain and the United States operational research was successfully applied, after the war, to the problems of industry—to the running of transport systems, civil aviation and traffic problems, as well as to many

[3] Sqn Ldr A. D. Thomas, MSc; RAAF. Communications engineer; of Burwood, NSW; b. Richmond, Eng, 13 Jun 1921.

other fields of activity. Despite the useful work done in the R.A.A.F., there were long delays in applying the technique to Australia's peacetime activities. Bowen's study of the problems relating to the stacking of aircraft over an airport,[4] and Muncey and Hutson's work on floor temperatures[5] were among the first applications of the technique to civilian problems.

[4] E. G. Bowen, "Operational Research into the Air Traffic Problem", *Journal of the Institute of Navigation*, Vol. 1 (1948), p. 338.

[5] R. W. Muncey and J. M. Hutson, "The Effect of Floor on Foot Temperature", *Aust Journal of Applied Science*, Vol. 4 (1953), p. 395.

CHAPTER 29

THE TEN YEARS AFTER THE WAR

THE nation's great industrial effort reached its climax towards the end of 1943. By reason of the great momentum it had gathered, industry continued, in some instances, to produce munitions that were in excess of requirements. This was inevitable. In modern industry the "tooling up" process is a long one; the productive machine gathers momentum slowly; but once in motion it cannot be stopped suddenly without great dislocation. Some activities of the Munitions Department, such as the manufacture of small marine craft, continued with undiminished intensity practically to the end of the war but after 1943 the general trend was to transfer as much as possible of the nation's effort to the production of food.

Early in 1945, when victory seemed assured, many of the industrialists who as chiefs of the various directorates of the Department of Munitions and members of the Boards of Area Management, had freely placed their services at their country's disposal, began to return to their peacetime responsibilities. This must not be taken to imply that the whole organisation of commercial industry for war was abandoned so early; what it meant in general was that one or other of the business men retired in favour of a deputy, who was usually a public servant. The nation had reason to be grateful to all who had helped the industrial effort, especially to Mr Lewis, its great leader. His services had already received official recognition: in September 1943 His Majesty the King had admitted Lewis to the Order of Companion of Honour, a rare distinction.[1]

For a country whose population was only about 7,000,000 and whose natural resources were, with a few exceptions, by no means abundant, the record of its wartime industry was in many respects a remarkable one. Nearly everything—factories, equipment and material—had to be created out of the country's resources; in many instances factories had first to be built to make the equipment and materials. Of course there were occasional mistakes and failures, but no more than would be expected in any large enterprise. All in all Australia could justly take pride in the achievements of her industries.

While it is natural that the history of military campaigns should be confined fairly closely to events within the duration of the war of which they form a part, the continuity of the growth of science and technology is such that its history demands a somewhat less restrictive treatment.

In order, therefore, to give some symmetry to this account, which began by tracing the pre-war growth of scientific organisations and industries which contributed to the war effort, it is proposed in conclusion to examine

[1] The citation said: "No Australian has given more unreservedly of his services and talents in the service of this country or rendered greater service in the production of weapons for the defence of Australia and other parts of the Empire."

briefly some of the more immediate consequences of the industrial and scientific changes that took place during the war, and the efforts made to restore and reconstruct what the war had disorganised.

Many questions arise to which the reader might reasonably expect some answer: were the serious gaps in Australia's self-sufficiency—the absence of ingot aluminium and tinplate manufacture, for example—filled in the years immediately following? What became of the government munitions factories and annexes built in the war years? How did the experience gained by private firms in the manufacture of munitions influence subsequent industrial development? How many of the new industries begun during the war survived it? Did the experience gained in maintaining armies in the tropics have any influence on the development of northern Australia? How soon were the threads of fundamental scientific work dropped because of the war taken up again? What became of the large team of radio-physicists built up to develop radar? What happened to servicemen who, owing to the war, were deprived of their opportunities to undergo scientific and technical training?

The Commonwealth Reconstruction Training Scheme. As early as March 1943 the Government began to make plans for the rehabilitation of servicemen. Among the reasons for making an early start on this problem was the necessity for sustaining the morale of soldiers during the long periods of enforced inactivity on the fighting fronts. They inevitably speculated about their future in civil life and it was important to allay as far as possible their doubts and anxieties. For the purpose of administering the professional and vocational training of servicemen and ex-servicemen, the War Cabinet appointed in 1943 the Commonwealth Reconstruction Training Committee.[2] A comprehensive scheme, based to a large extent on the very successful one devised by Mr J. Nangle in 1919,[3] was evolved and put into operation, on a limited scale, before the war actually ended.[4] In the early phase of its activity the new scheme, known as the Commonwealth Reconstruction Training Scheme, was concerned mainly with correspondence courses conducted by various Australian universities, most of which set up departments of external studies for servicemen and ex-servicemen. No serious training of scientists and technicians could have been done by this method, nor was it attempted.

To all who had missed educational opportunities owing to war service; to those unable to return to their old occupations by reason of incapacity caused by the war; to those who had interrupted their courses to enlist or had enlisted under the age of twenty-one; and to such deserving people as war widows, the Government offered educational opportunities, not as a reward for service but as a right, to enable them to take their

[2] Members were: Dr H. C. Coombs (Director-General of Post-War Reconstruction); E. P. Eltham (Dept of Labour and National Service); C. B. Smith (Repatriation Commission); Prof R. C. Mills (Chairman, Universities Commission); and from the Services Col R. B. Madgwick and W Cdr J. R. Gordon.

[3] Presidential Address, *Proc Royal Society of N.S.W.*, Vol. 55 (1921).

[4] From 1 Feb 1944.

place in civil life once more. Men and women within these groups were required to provide evidence that they could reasonably expect to profit from the courses they sought to take. Vocational guidance centres established within the armed services were extensively used in the selection of trainees for the Commonwealth Reconstruction Training Scheme, but only occasionally in selection for professional training;[5] admission to professional training required, as always, a specific level of educational achievement, namely matriculation. At the vocational level, however, the psychological services contributed much to smoothing the transition processes. Many of the senior officers of these services afterwards found their civil occupations in related fields, and were thus able to bring their wartime experience to bear on similar problems of peacetime organisation.[6]

Fields of training were divided among different authorities. The Repatriation Commission assumed responsibility for the training of blinded ex-servicemen and those who had been so disabled by war service that they could not profit from ordinary methods of training. Eltham, as Director of the Commonwealth Technical Training Scheme, administered the vocational training scheme generally, including all the forms of trade training carried out in technical colleges. The emphasis which in the Defence Training Scheme had been on engineering trades was now shifted to the building trades in order to make up the leeway in domestic building created by the war. Responsibility for all training at the university level rested with the Universities Commission, which had already gained experience in this field by supervising the enrolment of "reserved" students and administering the Commonwealth's financial assistance scheme.

Having already committed itself to assisting education during the war, the Commonwealth Government shouldered the very considerable financial burden of the Reconstruction Training Scheme. Since, with the exception of the University of Western Australia, the State universities were private institutions, it was necessary to allot large sums of money to the universities in the form of subsidies, to meet the actual cost of tuition and students' fees. Living allowances paid to students to ensure an income while training, and allowances for books and scientific equipment, cost the Government upwards of £7,000,000. Assistance was given not only to university students but also to students attending full-time day courses in science, engineering and architecture at technical colleges and to those preparing for matriculation. It is pleasing to be able to record that, in general, university teachers were impressed with the maturity of outlook of ex-service students; their relative success at the university was high.

Within the universities the effect of the Reconstruction Training Scheme was felt mostly in the faculties of science, engineering, medicine and veterinary science, whose resources were so severely taxed that it became

[5] A full report of the RAAF's extensive activities in this field is to be found in its publication *Vocational Guidance in the RAAF, 1942-46*, by W Cdr J. F. Clark and Sqn Ldr T. G. Jones.

[6] For instance, J. F. Clark became Professor of Applied Psychology at the NSW University of Technology; S. C. Derwent, Personnel Inspector of the NSW Public Service Board; D. E. Rose and E. Blomgren, Vocational Guidance Officers in the Youth Welfare Section of the NSW Dept of Labour and Industry.

imperative to erect new buildings and to obtain much new equipment. The Government agreed to meet the cost of all temporary buildings needed, on the understanding that they were to be disposed of at the end of the scheme. However it was not long before the disadvantage of temporary arrangements of this kind became apparent and a new agreement was reached that, wherever possible, the buildings and equipment were to be permanent and to be taken over at the end of the scheme by the universities on a basis to be determined by the Commonwealth, the States and the universities. By 1949, 85 per cent of the buildings so erected and 93 per cent of the new equipment were classed as permanent additions to the universities. Of £1,000,000 spent on buildings, less than £150,000 was spent on temporary structures, most of which appear to have been concentrated within the grounds of the University of Sydney, where they were sometimes jocularly referred to as the "Wallace Collection", after the then Vice-Chancellor, Sir Robert Wallace. Special provision was made to enable universities and technical colleges to obtain equipment for teaching purposes through the Disposals Commission at a small fraction of its real value.

Much help was given to ex-service students in meeting difficulties arising in the course of their rehabilitation, by guidance officers who were appointed at all universities. By 1948, when the Reconstruction Training Scheme reached the peak of its activity, the student population of Australian universities had risen from its pre-war level of 14,000 to 30,000, and of the technical colleges from 88,000 to 145,000.[7] Of the 44,662 courses begun under the Reconstruction Training Scheme 20,519, of which 14,661 were full-time and 5,858 part-time, were completed by September 1953. The high rate of wastage implicit in these figures caused some concern to educational authorities.

With the object of helping capable students who might otherwise have been unable to obtain a university education the Government, in 1943, introduced the Commonwealth Financial Assistance Scheme. In the following year students undertaking full-time courses in technical colleges were brought within its ambit. This form of assistance, granted to civilian students on the basis of a means test, was continued after the war. Out of it grew the Commonwealth Scholarship Scheme, under which 3,000 scholarships were awarded annually to students about to enter universities, technical colleges and other training establishments.

In the course of its efforts to rehabilitate servicemen, the Commonwealth, especially through the agency of the Universities Commission, did much to broaden the educational horizons of Australia. Few educational authorities would agree that "the doors of all universities throughout the Commonwealth are open to all able students";[8] most, however, would agree that the doors were much wider open than they were in 1939.

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[7] If students doing correspondence courses are included the figures are 91,000 and 163,000 respectively.

[8] "Opening University Doors", the story of the Universities Commission. Issued by the Dept of Post-war Reconstruction, 17 Oct 1949.

Investigations in New South Wales, for instance, showed that the biggest losses of ability to the universities and other institutions of higher learning occurred lower down on the educational ladder. Only one in three of the boys and girls whose intelligence quotients indicated that they would be likely to profit from a university training remained at school after the intermediate certificate examination or its equivalent. Thus despite the advances made during and since the war in equalising educational opportunity, the community was in 1956 still far from making efficient use of latent scientific and technical talent.

The Rise of Specialist Universities. The contribution of Australian universities to many scientific and technical phases of the war effort (in optical munitions, drugs, tropic proofing, radar and aeronautics to mention only a few instances) led to a deeper appreciation by the Government of the influence of these institutions on the industrial development and defence of the country. Consequently governments were more easily persuaded to give their support to the development of science and scientific institutions than they had been before the war. Two important features were missing from the scheme of higher education in Australia, namely universities devoted mainly to postgraduate studies, and universities or institutes devoted primarily to higher technological studies. Within a year or so of the end of the war both deficiencies were made good, the former by the foundation of the National University at Canberra, the latter by the establishment in Sydney of the New South Wales University of Technology.

One of the hopes of the founders of the Federal Capital had been that some day it would become a centre of learning as well as of government, but many years were to pass before this became a reality. In 1944 while on a visit to Australia for the purpose of advising the army on the use of penicillin, Sir Howard Florey was invited by the Prime Minister, Mr Curtin, to report on a proposal for the establishment of a national centre for medical research. Florey was wholeheartedly in favour of the idea. While he was preparing his report a committee which had been appointed to inquire into the Commonwealth's responsibilities in education suggested that the Government should set up a postgraduate university for social sciences. Out of these two proposals grew the idea of a national university.

Many circumstances contributed to foster the growth of the idea. The State universities were doing their share in training graduates for the professions, but in the opinion of authorities on higher education they were not doing enough to foster postgraduate studies. The output of fundamental scientific work, which had inevitably fallen off during the war, began to recover in the years immediately following, especially after a number of universities instituted, for the first time, the degree of doctor of philosophy; but research was considerably hampered by the lack of funds and by the large numbers of undergraduate students with which the universities were then swamped. The ratio of staff to students in Australian universities (1 to 20), which compared unfavourably with those in other countries (1 to 10 in Britain and as low as 1 to 4 in some American institutions) indicates

how unsuitable conditions were for scientific research. As a general rule, the smaller the ratio, the better the conditions. In proportion to her population, Australia was sending more students overseas for advanced scientific training than probably any other country.

The Federal Government was spending more on applied science than on pure science. The C.S.I.R.O., for example, received approximately £3,000,000 a year, whereas the total university expenditures on scientific research financed from Commonwealth funds was only of the order of £100,000. Considerations such as these provided powerful arguments in favour of a national university devoted to postgraduate studies.

Curtin did not live to see the new university. His successor, Mr Chifley, a no less enthusiastic supporter of the plan, and the Minister for Post-War Reconstruction (Mr Dedman[9]) pressed forward eagerly with the proposals. Two leading public servants, Dr Coombs,[1] Director-General of the Department of Post-War Reconstruction, and Professor Mills,[2] Chairman of the Universities Commission, took a prominent part in planning the new university. It was established, with the full support of all political parties, in August 1946 under the *Australian National University Act, 1945*. The Act provided for the setting up of an Interim Council[3] to guide the university through its formative stages; it also provided for the organisation of the university into four main research schools. Appropriately enough, the Medical School was named after John Curtin; added to it were the Research Schools of Physical Science, Social Science, and Pacific Studies. One of the first acts of the University Council was to elect Viscount Bruce as Chancellor. This was fitting recognition of the services he had rendered to the cause of science while he was Prime Minister in the late twenties. Sir Douglas Copland,[4] who during the war had been the Commonwealth Prices Commissioner, became the first Vice-Chancellor.

The contemporary politician's faith in the significance of scientific research in national development was evident from the generous provision of funds for buildings and for the construction of such unusually expensive equipment as the synchrotron designed by Professor Oliphant, the first Director of the Research School of Physical Science.[5] This school, together

[9] Hon J. J. Dedman. (Served British and Indian Armies 1914-22.) MHR 1940-49; Min for War Organisation of Industry 1941-45, Post-War Reconstrn 1945-49, Defence 1946-49. Of Geelong, Vic; b. Newton Stewart, Scotland, 2 Jun 1896.

[1] H. C. Coombs, MA, PhD. Economist to C'wealth Treasury 1939; Director of Rationing 1942; Director-General Post-War Reconstruction 1943-49; Governor, C'wealth Bank, since 1949; Chairman, C'wealth Bank Board, since 1951. B. Kalamunda, WA, 24 Feb 1906.

[2] R. C. Mills, OBE; LLM, DScEcon. (Served RGA in first world war.) Prof of Economics, Univ of Sydney, 1922-45; Chairman, C'wealth Grants Commission, 1941-45; Chairman, Universities Commission, 1942-52; Director, C'wealth Office of Education, 1942-52. B. Ardmona, Vic, 8 Mar 1886. Died 6 Aug 1952.

[3] Consisting of: Prof R. C. Mills (Chairman), John Medley (Vice-Chairman), Sir Robert Garran, Sir David Rivett, Sir Frederic Eggleston, Prof R. D. Wright, C. S. Daley, Prof E. Ashby, Dr H. C. Coombs, Prof K. H. Bailey, H. J. Goodes, Prof Douglas Copland, Prof H. K. Ward, Dr J. G. Wood, Prof L. H. Martin, A. S. Brown, K. E. Beazley, MP, Senator Hon Walter Cooper, Senator Hon J. H. O'Byrne, Hon Percy Spender, MP.

[4] Sir Douglas Copland, KBE, CMG; MA, DSc, LittD, LLD. Prof of Commerce and Dean of Faculty, Univ of Melbourne, 1924-44, Prof of Economics 1944-45; C'wealth Prices Commissioner 1939-45; Vice-Chancellor, Aust National Univ, 1948-53; Aust Min in China 1946-48; Aust High Commnr in Canada 1953-56; Principal, Aust Admin Staff College, since 1956. B. Timaru, NZ, 24 Feb 1894.

[5] The cost of this equipment was estimated at roughly £500,000.

with a Section of Atomic Physics formed in the University of Melbourne by the C.S.I.R.O., a School of Nuclear Research built up within the University of Sydney, and the Institute of Nuclear Engineering formed by the N.S.W. University of Technology, soon placed Australia in a position from which she had every prospect of being able to play her part in the exploitation of atomic energy. That the Government intended to take its full share of responsibility in developing the use of atomic energy was made plain in November 1952 when it set up the Australian Atomic Energy Commission, one of whose major projects was the construction of an experimental nuclear reactor at Menai, New South Wales.

The New South Wales University of Technology. It was no accident that the move for higher technological education in Australia first succeeded in New South Wales. Within the scope of its diploma courses, the Sydney Technical College had for many years provided valuable training in a wide range of technological studies, but it could make no provision for degrees in these subjects; this restricted its contribution to research. A feature of the New South Wales diploma courses which distinguished them from those of Victoria, for example, was the higher standard required for entrance. This standard, which was about that required for entrance to a university degree course, greatly facilitated the transition from a technical college to a university. The academic status of some of the New South Wales diploma courses was attested by the recognition they received from oversea professional organisations. To take but one example, the diploma in chemistry was officially recognised by the Royal Institute of Chemistry of Great Britain and Ireland. The Sydney Technical College enjoyed the distinction of being the only technical college in the British Commonwealth outside the United Kingdom to have its diploma in chemistry so recognised.

In the late thirties the large body of diplomates and students of the Sydney Technical College, aware of the high opinion that industry held of many of its courses and anxious to see an improvement in the academic status of its studies, strongly supported a movement for the establishment of an institute of technology empowered to grant degrees. This movement, led by Dr R. K. Murphy,[6] had been in existence for many years—ever since the early twenties—but it was not until early in the war that there seemed to be any prospect of its succeeding. The New South Wales Minister for Education, Mr Drummond, had returned from a tour of Germany and other European countries impressed with the need for improving the State's system of technical education. Speaking in support of a Technical Education Bill (No. 2) introduced on 14th March 1940, he pointed out that there had been no major development in the State's system of technical education since the 1914-18 war, and that the system was failing to meet fully the requirements of the country's expanding secondary industry. The most revolutionary of the bill's three clauses was

[6] R. K. Murphy, Dr-Ing. Head of Science Dept, Sydney Technical College, 1914-44; Principal, Sydney Technical College, 1945-52; Chemical Adviser to the Army; Lecturer in Chemical Engineering, NSW Univ of Technology, 1952-56. B. Newark, NJ, USA, 29 Jul 1887.

the one providing for the establishment of a new organisation devoted to higher technological education, to be known as the N.S.W. Institute of Technology. Despite some determined opposition, on the ground that it would allow certain industrial monopolies too great a say in the State's technical education policy, the bill was passed and was assented to on 25th September 1940. However before it could be implemented there was a change of government and the project was abandoned indefinitely.

It was not revived until after the war, when several new influences were at work. There was firstly the lesson of the war itself. Authorities in Britain were of the opinion that the cost of the war had been unnecessarily high and its duration unnecessarily prolonged because of defects in that country's provision for higher technological education. In a similar, but less critical way, Australia's industrial effort had been less efficient than it might have been. Educational and government circles in New South Wales were also greatly influenced by several reports arguing the need for extending the facilities for higher technological education in Britain.[7] The opportunities to be found in the rapid expansion of secondary industry after the war offered a powerful inducement to extend the scope of higher technological education.

In 1946 the Minister for Education in New South Wales, Mr Heffron,[8] took the opportunity of consulting Dr Karl T. Compton, President of the Massachusetts Institute of Technology, who was then on a visit to Australia. Compton, who had visited Australia on wartime missions for the Office of Scientific Research and Development, had no difficulty in convincing Heffron that one of the important factors contributing to the United States' world leadership in technology was the attention paid to scientific and technological education. Shortly after Compton's visit, the State Cabinet agreed in principle to the establishment of an institute of technology and approved Heffron's proposals for the appointment of a developmental council.[9] This body, of which Heffron was chairman, met for the first time on 27th August 1947, and began to formulate a general plan for the new institute. Much of the subsequent detailed planning was done by Mr Denning[1] in his capacity as acting Director.

Since there was little prospect of being able to erect buildings within a reasonable time—the wartime lag in home building had not yet been overcome—it was decided to use the facilities of the Sydney Technical College until such time as a program of new construction could be under-

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[7] "Higher Technological Education", Report of the Special Committee appointed April 1944 under the chairmanship of Lord Eustace Percy, presented to the Minister for Education. HM Stationery Office (1945).
"Scientific Manpower", Report of the Committee appointed by the Lord President of the Council, Command G 824, under J. A. Barlow. HM Stationery Office (1946).
"Colleges of Technology and Technical Manpower", Report of Parliamentary and Scientific Committee (1947).

[8] Hon R. J. Heffron. MLA, NSW, since 1930; Min for National Emergency Services 1941-44, for Educ and Child Welfare since 1944. Of Sydney; b. Thames, NZ, 10 Sep 1890.

[9] To consist of: W. E. Clegg, H. G. Conde, A. Denning, J. P. Glasheen, Dr R. W. E. B. Harman, R. C. Harrison, W. G. Kett, J. N Kirby, Prof R. J. W. Le Fevre, J. G. McKenzie, F. M. Mathews, R. G. C. Parry Okeden, P. D. Riddell, Prof S. H. Roberts, R. J. Webster and F. Wilson.

[1] A. Denning, BSc. Deputy Superintendent, Technical Education NSW, 1945; Director NSW Univ of Technology and Director Technical Education NSW, 1949. Of Sydney; b. Sydney, 23 Apr 1901.

taken. The first courses were instituted in 1948. By the end of the year the institute had assumed a sufficiently definite form to inspire the full confidence of the Government, and on 1st July 1949 the New South Wales University of Technology was incorporated by Act of Parliament.

The proposal was to call the new body the New South Wales Institute of Technology following American precedent, but despite the fact that much of the earlier planning had been inspired by the well-known American institutes of technology, confidence in the appropriateness of this title waned and, at the last moment, Parliament acting on suggestions from Britain, changed the name to the New South Wales University of Technology. This of course did not alter its character or its aims, or the fact that the foundation of the new university was one of the most significant developments in Australian education in the present century. Its aim was to provide specialised instruction, advanced training and opportunities for research in various branches of science and technology and in their application to commerce and industry. In giving effect to its decision the Government made large grants of money, in the first instance for equipment, but within a year or so for buildings as well. Mr W. C. Wurth, who it will be recalled was the wartime Director-General of Manpower, became the University's first Chancellor and Professor J. P. Baxter[2] its first Vice-Chancellor. The foundation stone of the first major building on the site reserved for the university at Kensington was set on 25th February 1950, by the Governor of New South Wales, Sir John Northcott

In the course of its development the University of Technology retained some of the traditions and characteristics of its parent body. For the first few years of its existence appointments to its scientific staff were made by the Public Service Board, but on 1st July 1954 this interim arrangement, as provided in the 1949 Act, was superseded and the University of Technology then achieved a level of autonomy comparable with that of other Australian universities.

The Australian Academy of Science. Throughout its relatively short life the Australian National Research Council (A.N.R.C.) managed to do many things for science but it did not win, in government circles at least, the high prestige attained by similar bodies in other parts of the world. Governments, as a rule, did not turn spontaneously to it for advice. Whenever the Commonwealth Government accepted the council's advice—as it did on a number of occasions during the war—it was nearly always the council that took the initiative in offering it.

The inability of the A.N.R.C. to become the consultant of the Government on scientific matters was due mainly to factors peculiar to Australia. The national academies and societies in the older countries were established two or three centuries ago, when governments were as yet unaware of the potentialities of science. As the fame of the discoveries of their members grew, the academies acquired honour and prestige. In such

[2] J. P. Baxter, OBE; PhD, BSc. Research Director-General Chemicals Division ICI Ltd to 1949; Prof of Chemical Engineering, NSW Univ of Technology, 1949-52, Vice-Chancellor since 1953. B. Machynlleth, Wales, 7 May 1905.

countries present-day government scientific departments were greatly influenced by, and in many instances owed their existence to, these old and respected academies. The A.N.R.C., on the other hand, had the misfortune to be born about the same time as the Council for Scientific and Industrial Research. It was natural that the government of the day should tend to consult and support its own offspring and to reject the advice of the A.N.R.C. if this differed from that of the C.S.I.R., as it occasionally did.[3] The A.N.R.C. provided the only machinery whereby the Government could have established contact with representative leading scientists outside its employ, but little use was made of it.

The record of the A.N.R.C's service to science was one from which it could take some satisfaction. As the body through which Australia adhered to the various international scientific unions it enabled the country to fulfil its obligations to the larger world of science. To it must go the credit for persuading the Government to set up the wartime Scientific Liaison Bureau, the Scientific Section of the Directorate of Manpower, and the Mineral Resources Survey. Soon after the war, in cooperation with the C.S.I.R., it founded the first national journals of physical, biological and applied science, an event which, as much as any other, marked the coming of age of science in Australia. Despite all these activities it failed to acquire the influence expected of a fully effective national body. The main reason for this was lack of money, which acting in a vicious circle circumscribed its activities and thus the prospect of gaining any stronger financial support from the Government. At no time was the A.N.R.C. able to maintain a fully staffed secretariat or to bring together at reasonably frequent intervals representatives from all States.

At last, convinced that there were no prospects of obtaining stronger government support for the A.N.R.C., a small group initially composed of eleven Fellows of the Royal Society—of whom Professor Oliphant and Dr Martyn were the leading spirits—decided to found an Australian academy of science modelled closely on the Royal Society. The decision was taken only after several conferences with the Executive of the A.N.R.C. The latter, after consulting its members, announced that if the attempt to launch an adequately financed national academy succeeded, there would no longer be any reason for its own existence, and that in due course it would retire from the scene.

The academy was planned to be a more select body than the National Research Council and less unwieldy, comprising fifty or sixty of Australia's outstanding scientists.[4] Its founders were faced with the same problem that had beset the A.N.R.C.: how could a newly-founded, national academy, relying on Commonwealth funds, secure and preserve the independence of outlook vital to the welfare of science? Having convinced

[3] The rejection of the ANRC's advice to form a scientific advisory council, which was mentioned in Chapter 3, is an instance.

[4] The first council was: President, Prof M. L. Oliphant; Treasurer, H. R. Marston; Secretary (Physical Sciences), Dr D. F. Martyn; Secretary (Biological Sciences), Dr A. J. Nicholson; Ordinary Members: Prof T. M. Cherry, Prof Ian Clunies-Ross, Prof J. C. Eccles, Prof R. J. W. Le Fevre, Sir Douglas Mawson and Sir David Rivett.

the Prime Minister, Mr Menzies, that they had found an answer to this problem, and having been assured of an annual grant sufficient to support the academy, the group of founders invited ten other leading Australian scientists to join them in petitioning for a Royal Charter. Through the intervention of the Prime Minister and of the Royal Society of London, the petition was considered and approved by a specially convened meeting of the Privy Council on 12th January 1954. At a ceremony in Canberra on 16th February 1954 Queen Elizabeth II presented the Royal Charter to the Officers and Council-elect of the Australian Academy of Science. This was the first time in nearly 300 years that the Sovereign had founded a scientific society, the only precedent being the foundation of the Royal Society by Charles II.

Once the academy had been launched, the A.N.R.C. took steps to bring about its own dissolution, a process which was completed at a meeting of the Executive Council presided over by Professor Elkin[5] on 28th October. And so, after a quarter of a century of service to science, the A.N.R.C. gave way to its successor.

The Commonwealth Scientific and Industrial Research Organisation. In the period of rearmament immediately after the war, many governments, conscious of the growing importance of science in warfare, were faced with the dilemma: how far should scientific research conducted under their auspices be kept secret. The Australian Government did not escape its worries on this score. Sir David Rivett, who as Chief Executive Officer of the C.S.I.R. had been intimately associated with the formation of the Radiophysics Laboratory and with the precautions taken to safeguard the secrecy of its work, was strongly opposed to the idea that his organisation should continue secret work in peace time. In this he was on firm ground since the *Science and Industry Research Acts (1926-39)* under which the council had been established, gave it no authority to engage in defence work of the kind for which strict secrecy was essential. The Radiophysics Laboratory gave up secret work, but the Division of Aeronautics, also essentially a wartime creation, continued with it and seemed likely to become more and more deeply involved, especially after the Long Range Weapons Project had been set up.

Without any warning to the council of its intention the Commonwealth Government brought down a bill in December 1948 "empowering it to transfer any part of the work of the Council irrespective of its connection with defence, to the control of various Government departments under the Public Service Board".[6]

To scientists the transfer to a government department of a division closely related to defence—such, for instance, as the Division of Aeronautics—seemed reasonable enough, but they viewed the possibility of a wholesale transfer "as a step of the profoundest gravity and importance

[5] A. P. Elkin, MA, PhD. Clergyman of C of E Diocese of Newcastle, NSW, since 1915; Prof of Anthropology, Univ of Sydney, 1934-55. B. West Maitland, NSW, 27 Mar 1891.

[6] Statement issued by the C.S.I.R. and quoted in *Australian Journal of Science*, Vol. 11 (1949), pp. 147 and 151.

to Australia and Australian science". They took this view not so much because of the threat of the imposition of secrecy inherent in such a transfer, though this was constantly in mind, but because they felt that the direct political control the C.S.I.R. would be subjected to as a department of the Public Service would be disastrous to the development of science. The independence upon which the C.S.I.R. had for so long prided itself, and to which its great record of successful scientific work over the previous 20 years owed so much, was in jeopardy.

Alarmed at the trend of events, the Australian National Research Council protested to the Minister for Post-War Reconstruction, Mr Dedman, pointing out the dangers to the well-being of science implicit in the wording of the Act. All protests were without avail as far as the Act of 1948 was concerned, but they did cause the Government to bring down another Act in April 1949.

In the debate on this Act, the issue of secrecy and military security, though not strictly relevant to the subject under discussion, was again introduced. One member of the Opposition in a violent and unjustified attack on the C.S.I.R. declared: "Scientists from their lofty pinnacle consider that their research discoveries should be made available to other nations but the Government must take a more practical view." He spoke as though this were an aberration of scientists, and one to which they had but recently succumbed. In fact, the history of science over the last 300 years shows that scientists have, as a basic principle, revealed their discoveries to all who were interested, whatever their nationality. All experience has shown that without full publication, free exchange of ideas, and the critical discussion of its discoveries and theories, there can be no progress in science. In the continued absence of these conditions there would be nothing left, as far as science was concerned, to "take a more practical view" about.

Much of the argument in the debate was obscured by astonishing and (to scientists) disconcerting confusion over secrecy as applied to fundamental science (a suicidal policy) and secrecy as applied to defence science (the application of scientific principles to the problems of war)—an entirely different matter.

The new Act on which the debate centred, the *Science and Industry Research Act 1949,* reconstituted the Council for Scientific and Industrial Research and changed its name to the Commonwealth Scientific and Industrial Research Organisation (the C.S.I.R.O.). The governing body of the organisation was to be the Executive, consisting of the Chairman and four other members, three of whom must be scientists. The Act also provided for an Advisory Council consisting of the members of the Executive, the Chairmen of the State Committees, and such other members as the Advisory Council, with the consent of the Minister on the recommendation of the Executive, should coopt by reason of their scientific knowledge. It was this change in the organisational pattern that led to the change in name. The Public Service Board would scrutinise the scientific staff in regard to loyalty, but appointments were made and conditions of

work and salary set out, by the Executive. The new Act gave the Executive and Advisory Council much more responsibility and initiative to direct the organisation's affairs than had the Act of 1948. Although the provisions of the 1948 Act which had alarmed many scientists remained in force, these new changes did much to relieve the general apprehension. The problem of military security in a scientific age is essentially one for the defence scientist and the armed services. With them it was allowed to remain.

Scientific research after the war. There were several fields in which the potentialities for research built up during the war were later exploited to great effect. Perhaps the most notable was radar. In no other branch of science had such a strong team of research workers been brought together: they were almost certainly more numerous than could, in ordinary circumstances, have been absorbed in working out the application of radar to civil aviation and marine navigation. It is therefore appropriate to ask what happened to these men in the next few years. Many who were members of the Radiophysics Laboratory remained with it and took part in an intensified attack on fundamental problems already begun towards the end of the war. Soon three important fields of research were developed: rain and cloud physics, radio-astronomy and the application of radar to air and marine navigation.

To a country noted alike for droughts and floods and still largely dependent for its prosperity on agricultural and pastoral industries, few natural phenomena are more important than rain. Yet at this time there was astonishingly little scientific knowledge of the fundamental processes at work in the formation of rain. It had been recognised as early as 1942 that radar would be a powerful tool for investigating phenomena of the atmosphere, especially the formation of and movements within clouds. Accordingly the laboratory's post-war program included research on the structure of rain clouds, measurement of upper wind velocities, and the determination of the position and velocity of thunderstorms. About this time Langmuir and Schaeffer in the United States became interested in the effects of introducing dry ice into clouds to form rain. Their first experiment produced a snowstorm in the higher regions of the atmosphere, but the snow vanished before it reached the ground. Similar experiments, for which the tools were already available, were begun at the Radiophysics Laboratory by a team working under Bowen's direction. This team was joined in 1946 by Dr E. B. Kraus, who visited Langmuir and Schaeffer on his way out to Australia. Studies had already been made, using centimetric radar equipment, of heavy storms which owing to the ability of water drops to reflect[7] radio waves could be detected up to distances of 100 miles. With radar it was easily possible to distinguish between rain and cloud.

[7] More accurately, to scatter radio waves. Ability to scatter radio waves increased very much with drop size.

On 5th February 1947 Kraus and Squires, working in cooperation with the R.A.A.F., made some interesting experiments on clouds over the inland regions near Bathurst, New South Wales. Selecting one cloud from among many very similar clouds, they seeded it with dry ice while observers at George's Heights in Sydney watched the proceedings on a radar scope. Some minutes after the seeding the Sydney observers picked up rain echoes in the vicinity of this cloud. No such echoes had been detected in the region before the experiments. Moving some twenty miles away, they selected another cloud, and the whole process was repeated with similar results; rain fell from the inoculated cloud but not from the neighbouring similar clouds. For the first time in history, clouds had been artificially stimulated to produce rain.[8] This work marked the beginning of an extensive research program on the physics of rain formation.

Although the discovery that radio waves were reaching the earth from outer space had been made as early as 1932,[9] nothing much was done to follow it up until after the war, by which time greatly improved radio techniques were able to provide equipment sufficiently sensitive to enable more thorough investigations to be made. With the aid of a system of radio receiver and aerial, which because of its close analogy with the corresponding optical instrument became known as a radio interferometer, Bolton and Stanley in Sydney discovered that some radiation came from a localised region in space approximating to a point source.[1] They then discovered other point sources of radiation. Since their positions did not correspond with those of any of the conspicuous heavenly bodies, these sources were called "radio stars".

In 1942, while scanning sunlit skies over England for enemy aircraft, radar observers had occasionally picked up peculiar signals quite unlike those usually obtained, which were ultimately traced back to the sun. Pawsey and his collaborators in Australia made the interesting discovery that these peculiar signals came from some form of vast electrical storm that took place above sunspots. Theoretical work by Martyn and the experimental work by Pawsey led to the development of a method for measuring the temperature of different parts of the solar atmosphere.[2] They discovered that the corona is at the fantastically high temperature of about 1,000,000 degrees.

These were only a few of the interesting discoveries made by Australian radiophysicists in the early post-war years which earned them world-wide recognition.[3]

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[8] E. B. Kraus and P. Squires, "Experiments on the Stimulation of Clouds to Produce Rain", *Nature* (1947), p. 489.

[9] K. G. Jansky, "Electrical Disturbances Apparently of Extraterrestrial Origin". *Proceedings of the Institution of Radio Engineers*, Vol. 21 (1933), p. 1387.

[1] J. G. Bolton and G. J. Stanley, "Discrete Sources of Galactic Radio Frequency Noise". *Nature*, Vol. 162 (1947), p. 141.

[2] D. F. Martyn, "Origin of Radio Transmissions from the Disturbed Sun". *Nature*, Vol. 159 (1947), p. 26.
J. L. Pawsey, "Observation of a Million Degree Thermal Radiation from the Sun at a Wavelength of 1.5 metres". *Nature*, Vol. 158 (1946), p. 633.

[3] A full account of these discoveries will be found in *Radio Astronomy* (1955) by J. L. Pawsey and R. N. Bracewell.

Steady though slow progress was made in the application of radar aids to commercial aviation. The slowness was disheartening to the radio-physicists, who worked out excellent devices for which there appeared little demand. This situation was not peculiar to Australia. It occurred all over the world and may have been inherent in the economic position of commercial aviation at the time. Nevertheless some progress was made and in Australia it owed much to the leadership of Bowen, whose efforts in developing aids to civil aviation were recognised in 1950 by the Thurlow International Award for Navigation "for the outstanding contribution to the science of navigation in the year 1950".

The holding of the 10th General Meeting of the Union Radio-Scientifique Internationale at the University of Sydney in August 1952 was another tangible recognition of the international reputation of Australian contributions to radio science. This was a unique occasion, being the first time that any international scientific body had met in Australia—or for that matter in any country outside Europe and the United States.

Australia's contribution to knowledge in the fields of physical sciences which had for so long been an insignificant trickle, now grew to proportions in keeping with the remarkable growth of her industries and the activity of her scientific institutions. For the first time students and scientists from other parts of the world began to come to Australia to work for higher degrees and to carry out researches in laboratories that had achieved a well-established international reputation.

Surveys of Scientific and Industrial Resources. The need for surveys of the country's scientific resources—its scientists, as well as the organisations and institutions in which they worked—was felt acutely during the war, and it was then that such surveys were made for the first time: a survey of scientists by the Directorate of Manpower, and of institutions by the Scientific Liaison Bureau. Despite the fact that it had every promise of being equally useful in peace time and that it would lose most of its value if not kept up to date, work of this kind was allowed to lapse for some years after the war and was not revived until 1951. Surveys based on, but more comprehensive than their wartime counterparts, were carried out by the C.S.I.R.O., and by 1953 there existed excellent directories of Australia's scientific societies, professional institutions and scientific and technical research centres.[4] One notable gap remained; there was no register of Australian scientists which might be expected in a time of emergency to contribute to the more efficient use of the national resources of scientific manpower.

The Mineral Resources Survey and Minerals Production Directorate which had been improvised to meet the exigencies of war, met a national need that did not disappear when the war ended. Surveys and investigations of strategically important minerals begun by these organisations

[4] These directories are: G. J. Wylie and Nona F. Lowe, *Australian Scientific Societies and Professional Associations* (1951); and *Directory of Australian Scientific and Technical Research Centres.*

during the war were continued and new ones undertaken. In January 1945, the Commonwealth Government made a radical change in its policy towards the search for oil. Instead of giving financial assistance to relatively small companies as it had been doing—a policy that had met with no success—the Government decided to encourage private enterprise by initiating geological and geophysical surveys which were to be followed later by test and scout drilling. The need for assistance of this kind in the exploration and development of mineral resources in general had been pointed out by the Mining Advisory Panel of the Secondary Industries Commission as early as 1944. Methods of geophysical prospecting then being employed were very rapid; that is, they enabled large areas to be covered in a relatively short time. They were, however, also very costly and required much special equipment. If each State had built up its own organisation for this kind of work it would not only have been uneconomical but there would have been considerable risk of overlapping. In these circumstances strong support was forthcoming, from the State Mines Departments and private mining companies alike, for a move to consolidate the advances made during the war by setting up a permanent organisation.[5] Accordingly, the Commonwealth Public Service Board on 11th June 1946, approved the formation of a body to be known as the Bureau of Geology, Geophysics and Mineral Resources with Dr Raggatt as its director.[6]

The bureau greatly extended geophysical prospecting for oil and also greatly intensified its search for the radioactive minerals of vital interest in the development of atomic energy. Typical of its activities about this time was the survey and investigation of the monazite content of the beach sands of Eastern Australia: this was one of the most extensive surveys ever undertaken of the resources of a single mineral in Australia. The reason was not far to seek. Monazite was the principal source of thorium, which, in a breeder reactor, could be transformed into fissile uranium (U^{233}). The discovery in 1954 of the first flow oil in the Exmouth Gulf region of Western Australia, and the uncovering of important deposits of uranium in South Australia, the Northern Territory and Queensland, owed much to the encouragement and preliminary geological reconnaissance work done by the bureau.

The Department of National Development completed the first really exhaustive survey of Australia's secondary industry.[7] The results of the survey, which dealt in a systematic way with the products of some 43,000 factories representing 200 major industries, were published in a large volume entitled *The Structure and Capacity of Australian Manufacturing Industry,* in 1952.

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[5] South Australia later set up a small geophysical unit but the Commonwealth continued to meet the major geophysical commitments of that State.

[6] The name was later changed to the Bureau of Mineral Resources, Geology and Geophysics.

[7] Prepared by the department's Division of Industrial Development.

National Standards. Owing to its preoccupation with problems related to the war, the C.S.I.R. deferred taking any steps to secure legal sanctions for Commonwealth standards of weights and measurements until the National Standards Laboratory was able to complete the necessary preparatory work.

The most permanent and reproducible of all standards of length are not those made by etching fine marks on bars of platinum-iridium or other stable alloys, but those provided by nature herself in the form of the wavelengths of light emitted by excited atoms; from sources of light stationary with respect to the observer, these wavelengths, so far as is known, never vary. Once the length of the Imperial Standard Yard of Great Britain had been measured in terms of the wavelength of the red spectrum line of cadmium (as it was in 1907) or some other agreed-upon line, measurements in terms of the Imperial Standard Yard could be accurately made in Australia provided there were available devices for measuring the working standards of length in terms of the wavelength of the appropriate spectral line.[6] Equipment of the most up-to-date kind was installed for this purpose in the National Standards Laboratory soon after the war.

Keeping abreast of trends in standards laboratories in other parts of the world where efforts were being made to set up a standard of time which, like the light waves chosen for length standards, would be absolutely constant, the National Standards Laboratory began work on the microwave spectroscopy of ammonia. The frequency of the vibration of hydrogen atoms in an isolated ammonia molecule of a given isotopic composition depends solely on universal physical constants, and is thus independent of all external circumstances. The energy associated with the vibration of the hydrogen atom is small enough to bring it within the range of microwave spectroscopy. This molecular frequency provides a unit of time more nearly constant than the period of the earth's rotation, and one that, like the light-wave standard, can be produced anywhere any number of times.[7]

For the standards of mass, reliance at this time was placed solely on man-made standards, and in pursuance of this policy the National Standards Laboratory acquired from the International Bureau of Weights and Measures a copy of the standard kilogram in platinum-iridium.[8]

In June 1948 the Commonwealth Government exercised its powers under the Constitution to pass the *Weights and Measures (National Standards) Act* (No. 29 of 1948). In several respects, particularly in its flexibility, the Act was in advance of similar Acts in other parts of the world. It did not, for example, define any standards. It did, however, give the Government power to make regulations under which standards could be defined, thus leaving open the possibility of changing the standards

[6] In 1953 the International Committee on Weights and Measures agreed that the time had come to "envisage favourably" a new definition of the metre based upon a wavelength of light from single isotope sources, but could not agree upon which wavelength. Different countries favoured different isotopes: the United States favoured a spectrum line produced by the mercury isotope Hg^{198}; Germany a line from the krypton isotope Kr; and the U.S.S.R. a line produced by an isotope of cadmium.

[7] A resonant frequency of the caesium atom was later found to provide a more satisfactory unit.

[8] Copy No. 44.

from time to time without changing the Act. The advantage of this arrangement was that it left the way clear to profit, without delay, from scientific advances in measurement. A Standards Commission consisting of five scientists[9] was set up to advise the Minister in charge of the Commonwealth Scientific and Industrial Research Organisation on the regulations and any changes in standards that might be deemed necessary.

Long-range Weapons Project. Soon after the war the United Kingdom, stimulated no doubt by the German exploitation of long-range rockets (V2) and their attempts to produce guided missiles, began work on similar lines. Very few guided missiles of any kind had been used during the war but by 1945 the developments of electronics and the invention of the pulsed jet engine had paved the way for their fuller exploitation.

In order to test long-range missiles, some large uninhabited area covering anything up to 100,000 square miles was essential. Early trials made by firing the missiles over the sea were not very satisfactory since in these circumstances it was impossible to recover them for inspection. The British Government arranged for the investigation of several areas in Commonwealth countries, and the choice was finally narrowed down to the frozen wastes of the Hudson Bay region of Canada and the vast desert area of Central Australia. A mission headed by Lieut-General Evetts[1] first visited Australia in 1945. Evetts returned to Australia in 1946 with a team of scientists, serving officers and others, to take part in directing the setting up of the range and associated activities. He commented on the great array of buildings and facilities in the Salisbury area. These, it will be remembered, had been erected during the war for the manufacture of explosives, at a cost of more than £5,000,000. There was nothing temporary about their construction: as in so many other munitions ventures, Mr Essington Lewis had had an eye to Australia's industrial future. Lewis had, of course, no notion of the use to which they would actually be put after the war, though he knew they would not be needed for explosives manufacture. Some of the buildings had been taken over by commercial firms when the Secretary of the Department of Munitions, Mr Jensen, intervened and persuaded the Government of the wisdom of retaining them for defence purposes.

On 19th November 1946 the Australian Prime Minister, Mr Chifley, announced that an agreement had been reached with the United Kingdom on the establishment of a rocket range. In describing details of the project a few days later, the Minister for Defence, Mr Dedman, said that the decision represented a first step towards implementing the plan under which Australia would make a larger contribution to the defence of the British Commonwealth. The Government, anxious to help in every way possible, decided that Australia's part in the Long-Range Weapons Pro-

[9] Prof L. G. H. Huxley, Dr G. H. Briggs, N. A. Esserman, F. J. Lehany and S. J. Proctor.

[1] Lt-Gen Sir John Evetts, CB, CBE, MC. GOC 6 British Div, Syria, 1941; Asst Chief Imperial General Staff 1942-44; Senior Military Adviser, Ministry of Supply 1944-46; Chief Executive Officer, Joint UK-Australian Long-Range Weapons Board of Administration, 1946-51. Regular soldier; b. Naini Tal, India, 30 Jun 1891.

ject should be administered by the Department of Munitions, and when this department was abolished in 1948 it made provision in the Act for its successor, the Department of Supply, to administer the project.

An organisation named the Long-Range Weapons Establishment was set up to include the facilities at Salisbury, an air base at Mallala operated by the R.A.A.F. (which was formerly an Empire Air Training establishment), and a range. The site finally chosen for the head of the range was the area now known as Woomera, some 6 miles from the township of Pimba on the Transcontinental Railway, from which it was possible to test weapons over a land distance of 1,000 miles or more. Water was supplied to Woomera by tapping the Morgan-Whyalla pipe-line that had been constructed during the war to allow the development of the steel and shipbuilding industries in South Australia. A 10-inch pipe was laid from Port Augusta, at the head of Spencer's Gulf, 120 miles north-west to Woomera. The whole project was a joint British-Australian effort, both countries contributing to its costs.

It is pertinent to ask whether the war eventually brought about any change in the general position of Australia in relation to the design and development of armaments. In so far as the Long-Range Weapons Project was an outcome of the war, the answer is Yes. With a few notable exceptions, such as the Owen gun, the Wackett bomber and the short 25-pounder, little had been achieved in the way of new designs during the war of 1939-45. It is true that in a number of instances scientists and engineers had made important modifications to British and American designs of radar, aircraft and tanks, as in the long-range air-warning set, the Wirraway trainer and the Australian cruiser tank; but none of these was adopted throughout the British Commonwealth.

The original intention was to use the Rocket Range solely for testing weapons designed and developed in the United Kingdom. Now, it appeared, Australia was ready to consider seriously the possibility of undertaking research leading to new weapons. The existing facilities at the Defence Standards Laboratories (Maribyrnong) and the Aeronautical Research Laboratories (Fishermen's Bend) were insufficient to cope with the new plans. Consequently at Salisbury buildings known as the Chemical and Physical Research Laboratories were equipped for work in electronics, high-speed flight research and propulsion, and together with the Long-Range Weapons Establishment were placed under the direction of the Chief Scientist of the Department of Supply, Mr Butement.[2]

In the meantime numbers of young Australian scientists were sent to the United Kingdom to undertake postgraduate studies in fields likely to have some bearing on long-range and guided missiles. The last phase in the evolution of the Long-Range Weapons Project, and one of the greatest interest in relation to the history of the recent war, was a decision by the Government that Australia should herself take part in the design and

[2] W. A. S. Butement, OBE; BSc. Asst Director Scientific Research, British Min of Supply, 1940-46; Chief Superintendent Long-Range Weapons Establishment, Australia, 1947-49; Chief Scientist, Dept of Supply, since 1949. B. Masterton, NZ, 18 Aug 1904.

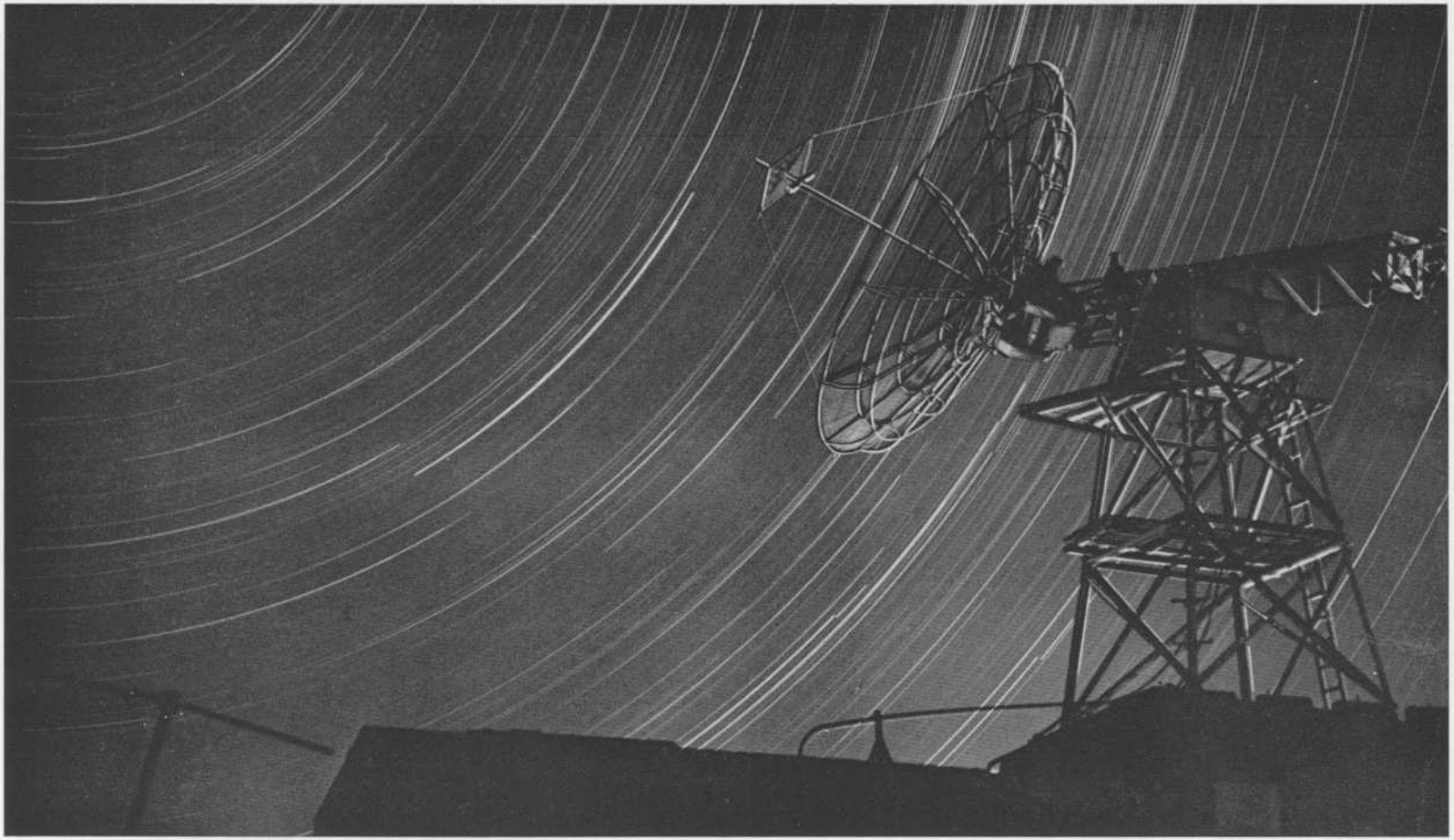
development of new weapons and the scientific research necessary thereto. Australia was no longer satisfied to rely implicitly on the United Kingdom but was eager to take her share in contributing new weapons to the common pool for the defence of the British Commonwealth of Nations.

The policy of defence science and the broad machinery for its implementation became the responsibility of a body set up within the Department of Defence, known as the Defence Research and Development Policy Committee. On this committee, which began its existence under the chairmanship of Professor L. H. Martin, scientists were strongly represented; it included several eminent civilian scientists, deputy chiefs of staff and chief technical officers of each of the Services, the Controller-General of Munitions and the Chief Scientist of the Department of Supply. Science thus became more closely integrated with the defence of Australia than it had been in the war of 1939-45.

Industry after the war. In 1943, while the war was still at its height, the Government began to consider what was to be done after the war with the numerous factories that had been built for the manufacture of munitions. It had already formed a Department of Post-War Reconstruction, which in turn recommended that a Secondary Industries Commission should be set up for the express purpose of advising the Government on the orderly transition of Australia's manufacturing from war to peace. The commission was fortunate in having as its chairman Mr Jensen, who had taken an important share over many years in developing the munitions factory construction program, and who was therefore able to give invaluable guidance in implementing the Government's decision to retain only a few of the factories permanently for defence purposes.

It is estimated that between 1940 and 1945 the Department of Munitions and its agencies spent at least £300,000,000. Much of this was used in producing articles that were expendable—guns and their ammunition, tanks and aeroplanes—which in the economic sense represented so much waste, but a good deal of it went into buildings and equipment destined to become permanent assets to the nation's industrial resources. Under the pressure of war a network of government factories for the manufacture of explosives, ammunition and small arms had been built not only in the industrial centres of the capital cities but in many country towns that hitherto had known little of manufacturing. Development of the latter was the result of two factors: the need to make the greatest possible use of rural manpower, and the need, where explosive factories were concerned, to consider the safety of civilian populations. One of the hopes of those who planned the rural factories was that one day they would become the spearhead of a great movement of industrial decentralisation. The number and area of wartime government munitions factories—urban and rural—are shown in the accompanying table.[3]

[3] Use has been made of a booklet issued by the Dept of Post-War Reconstruction entitled *Wartime Factories with a Peacetime Future: The Story of Industrial Decentralisation* (17 Oct 1949).



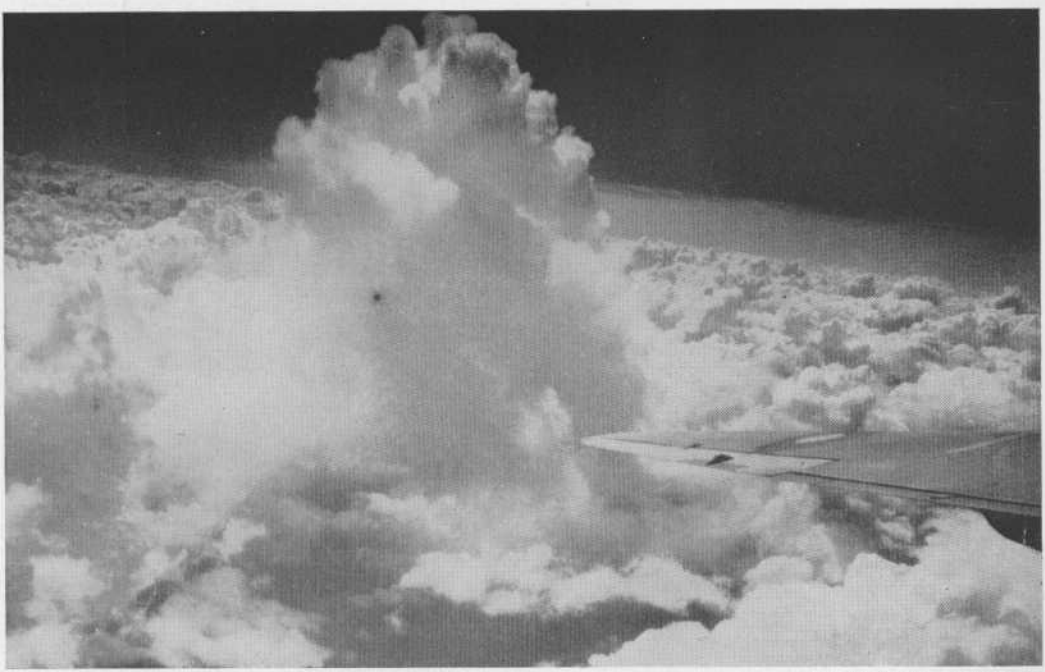
(*Radiophysics Laboratory*)

A radio telescope "listens" to radio waves from space as visible stars circle the sky, forming streaks of light in this 90-minute time exposure.



(*Radiophysics Laboratory*)

Artificial production of rain on 5th February 1947, over the Blue Mountains. The cloud base was at 11,000 feet, the freezing level at 18,000 feet, and the top of the clouds rather uniformly at 23,000 feet.



(*Radiophysics Laboratory*)

Thirteen minutes after the release of dry ice the top of the cloud had reached 29,000 feet. A few minutes later rain was observed visually, falling from the base of the cloud to the ground. Between 200 and 300 lb of dry ice were dropped into a selected cloud.

	Factory area (acres)	Expenditure authorised	No. of buildings
N.S.W.	6,972	12,276,280	1,402
Vic	4,266	6,509,400	1,160
Q'land	455	1,192,400	163
S. Aust	5,397	7,578,380	1,499
W. Aust	140	348,600	69
Tas	133	410,300	31
	17,363	28,315,360	4,324

The leading position occupied by New South Wales was, in the main, the outcome of its ability to provide the largest number of workers. Relative to size of population the greatest wartime industrial development took place in South Australia. The reason for this is to be found in considerations of defensive strategy. The figures in the table do not include 220 production annexes built as extensions to existing private factories, nor food dehydration factories, power alcohol distilleries, flax mills, aircraft production establishments and a great number of storage buildings.

The total area of wartime building construction disposed of by the Government was made up of the following types:

Munitions factories	6,190,274	square	feet
Munitions annexes	576,982	„	„
Aircraft production factories	381,719	„	„
Dehydration factories	179,216	„	„
Grain (power) alcohol distilleries	240,183	„	„
Flax mills	60,774	„	„
Warehouses	570,700	„	„
	8,199,848	„	„

Munitions factories built in widely scattered parts of the Commonwealth ranged from relatively small single buildings to huge concentrations of up to 1,000 buildings, totalling more than 1,000,000 square feet on one site.

The war years witnessed a development in the variety and complexity of manufacture and in technology generally, which might normally have occupied a much longer period. It was upon this that the great post-war expansion in secondary industry was built. At the end of the war there was a heavy demand for new factories and for houses. Few new houses were privately built during the last three years of the war.

The Government, anxious that factory building should not stand in the way of a vigorous housing program, pressed forward with its plans for disposing of the munitions plants. It was concerned that firms granted sales or leases should be of a kind able to make a useful contribution to the general pattern of manufacturing production in Australia.

The change-over of wartime factories to peacetime production had actually begun before the war ended. By 1946 some 120 individual enter-

prises had either bought or leased space in former munitions factories. Three years later this figure rose to 293. The accompanying table shows details of the disposals in each State and estimates of the employment likely to result from the establishment of new peacetime manufacturing projects.

	Area leased or sold (sq ft)	Estimated employment
N.S.W. . .	3,245,482	12,540
Vic . .	996,296	4,365
Q'land . .	1,364,312	3,691
S. Aust . .	1,789,102	5,557
W. Aust . .	395,187	1,456
Tas . .	409,469	1,677

The position occupied by South Australia is again worthy of note; relative to the size of its pre-war secondary industry, it profited most.

Former wartime factories now housed some of the largest manufacturing plants in the Commonwealth—such as woven rayon textiles, spare parts for motor-cars, radio and electrical equipment. They also provided the opportuntiy for beginning industries entirely new to the country: the manufacture of special types of machine tools, scientific equipment, special textiles and new chemicals. The fact that modern factory buildings together with all the necessary services and facilities were available for industrial purposes in country towns or in the less highly industrialised States, provided a strong inducement to firms already established in the large capital cities to decentralise their activities. The first, and what proved to be the largest, single disposal negotiated by the Secondary Industries Commission was the leasing of a former munitions factory at Rutherford, a small country town in the coalfields west of Newcastle, to Burlington Mills (Australia) Ltd, a rayon-weaving firm.

The firms which took advantage of the former war factories to decentralise to other States, included Philips Electrical Industries of Australia Pty Ltd, who transferred the whole of their works from Sydney to Hendon, South Australia; Oliver Nilsen Pty Ltd, of Melbourne, who opened a factory for electrical goods at Murray Bridge, South Australia; MacRobertsons Pty Ltd, of Melbourne, who established a branch of their confectionery business at St Mary's, New South Wales; Silk and Textiles Pty Ltd, of Sydney, who moved the whole of their activities to Derwent Park (near Hobart, Tasmania); and the Austral Bronze Company Pty Ltd, who transferred part of their operations to the same locality. In the former small-arms factory at Orange, New South Wales, Emmco Pty Ltd established a large factory employing more than 1,000 persons for the manufacture of refrigerators. The techniques of high-precision engineering once used for making small arms were transferred to the manufacture of "sealed units" for refrigerators.

Many well-known oversea firms took advantage of the disposal of war factories to provide space for their new Australian branches: Bruck

Mills (Australia) Ltd, closely linked with Bruck Mills of Canada, set up one of Australia's largest rayon weaving mills in a wartime aluminium fabrication plant at Wangaratta, Victoria; B. O. Morris Ltd, dental tool makers of Birmingham, established a subsidiary company at St. Mary's; Vactric Ltd, of England, established Vactric Electrical Industries Ltd at Finsbury, South Australia; there were also many others.

Disposal of factories comprising numerous buildings too large for a single enterprise, presented a special problem which was solved by setting up community industrial centres. One of the most notable examples of this kind was the Explosives Factory at St Mary's, a vast conglomeration of 900 buildings which covered 1,300,000 square feet and had cost nearly £5,500,000. The changeover at St Mary's began in 1946, and within two years eighty-nine firms, manufacturing a wide range of goods, became established there. While the government factory buildings were being transferred to private enterprise, town planners set about making St Mary's Australia's first satellite industrial township—a show-place of industrial activity.[4]

The four synthetic ammonia factories built to supply raw materials, chiefly nitric acid and ammonium nitrate, to the wartime explosives industry, were afterwards converted to produce ammonium sulphate for use as a fertiliser. These four plants, together with the first one erected by I.C.I.A.N.Z. at Deer Park, proved insufficient to meet Australian requirements, and a new and much larger plant was erected by the Electrolytic Zinc Company of Australasia at Risdon, Tasmania.

The Aluminium Industry. It will be recalled that in April 1944 an agreement was reached between the Commonwealth and Tasmanian Governments to establish an aluminium ingot industry in Tasmania.[5] A capital fund of £3,000,000, provided jointly by the two governments and estimated as sufficient for the construction of works capable of producing 10,000 tons of aluminium a year, was set up. The industry was entrusted to the Aluminium Production Commission, whose members were appointed in May 1945.[6] By this time the anxieties which had so harassed authorities in the aircraft industry had long since disappeared.

One of the commission's first acts was to extend the surveys begun by the Mineral Resources Survey, of the national reserves of bauxite. Proven reserves of approximately 21,000,000 tons of ore of economic grade were found, principally in the Northern Territory (Wessel Islands) and New South Wales, and brought within the commission's control.[7] This was

[4] Only a few years after this transfer had been completed the Government found it necessary to build a new explosives and filling factory at St Mary's.

[5] *Aluminium Industry Act No. 44 of 1944.*

[6] Members and deputy members of the Commission were as follows: Chairman, G. H. Watson (Mechanical and Designing Engineer); Deputy Chairman, L. R. S. Benjamin (Chemical Engineer); W. D. Scott (Consulting Accountant); W. H. Williams (Director of Mines, Tasmania); A. A. Topp (Chemical Engineer); H. B. Bennett (Director of Industrial Development in Tasmania); P. W. Nette (Asst Secretary, Commonwealth Treasury); and E. Parkes (Under Secretary, Premier's Dept, Tasmania).

[7] H. B. Owen, "Bauxite in Australia", Bulletin No. 24 Bureau of Mineral Resources, Geology and Geophysics, Dept of National Development.

ample for production for 150 years on the scale contemplated, and allowed a reasonable margin for expansion. Once supplies of the principal raw material, bauxite, had been guaranteed, provision of electrical power was the next vital step; it had already been decided to establish the industry in Tasmania because of that State's reserves of hydro-electric power.

After considerable technical investigation the commission decided to erect an electrolytic reduction plant near the mouth of the Tamar River at Bell Bay, which is accessible to vessels of large tonnage. A special scheme for providing electrical power, the largest single item in the cost of producing aluminium, was developed by the Hydro-Electric Commission of Tasmania at Trevallyn near Launceston.

Erection of the plant was begun in 1950, but before it was completed costs of construction had risen so sharply that an amending Act[8] was passed by the Federal Government increasing the Commonwealth's contribution to £5,750,000; this, together with the original contribution of £1,500,000 from Tasmania, brought the total appropriations for the project to £7,250,000. The amount was later increased to £10,500,000. This provided for increasing costs and also for an expansion of output to 13,000 tons of aluminium a year, to keep pace with increasing local demands.

The method of extraction adopted was the conventional Bayer-Hall process,[9] full technical advice upon which was supplied to the commission by the British Aluminium Company Ltd. With the exception of cryolite and petroleum coke, required to make the electrodes, all materials for the process were available within Australia. The principal—indeed almost the only—source of natural cryolite was Greenland. To safeguard the industry two steps were taken: stocks of cryolite were accumulated and an investigation into the problems associated with the production of synthetic cryolite was carried out by the CSIRO Division of Industrial Chemistry on a laboratory scale.

The plant was officially opened by the Prime Minister, Mr Menzies, on 23rd September 1955, five years after the first constructional work had begun. In spite of all the surveys of local sources of bauxite, the industry began by importing this raw material, mainly from Malaya: it was considered advisable to begin with a raw material whose characteristics were well known to the industry and which had been used in other parts of the world.

The Tinplate Industry. Dependence on imported tinplate continued for some years after the war. Two factors had militated against the earlier establishment of the industry: a chronic shortage of steel arising from post-war shortages of coal and labour, and technological changes in the industry itself. By the time the war was over it had become evident that the most economical raw material for tinplate was wide steel strip made

[8] No. 16 of 1952.

[9] Electrolysis of a melt of Al_2O_3 and Na_3AlF_6 with electrodes of the Soderberg type. Total current through the cells was 40,000 amps at 5 volts.

by a continuous hot-rolling process. Mills for this purpose were a costly item of equipment: during six years, beginning in 1948, Australian Iron and Steel Ltd spent approximately £35,000,000 on the installation of rolling mills to manufacture wide steel strip. Of the many uses to which tinplate could be put, the most important from the Australian standpoint was in packing primary products for the export market. The first wide steel strip was produced at Port Kembla by the continuous process in June 1955, just before this history ends, but production of tinplate was not then expected for another four or five years.

The manufacture of motor vehicles. Few industries did more towards arming the nation than the automotive industry; in the variety of its contribution (guns, bombs, shells, small marine craft, components for aircraft, torpedoes, aero-engines and diesel-engines) it was probably unrivalled. The need to find new outlets for the greatly expanded wartime engineering industry caused the Secondary Industries Commission at its second meeting, in December 1943, to consider the possible establishment of a motor vehicle industry in Australia. After the commission had completed its preliminary investigations on the subject and had communicated its findings to the Government, the Prime Minister, Mr Curtin, announced that the Cabinet had decided to repeal legislation that stood in the way of establishing a motor vehicle industry[1] and then, having intimated that if no private firm would build a car the Government itself would, he invited manufacturers to submit their plans. Owing to the reduction of imports of motor vehicles during the war years the number of vehicles available either for industry or defence had fallen to disturbingly low levels, and the Government, mindful of the importance of motor transport to the development of the country, was most anxious that some effort should soon be made to close this gap in Australia's self-sufficiency.

The first proposal received was that of General Motors-Holden's Ltd, which together with Curtin's reply thereto, was tabled in the House of Representatives in March 1945. The company proposed to manufacture in Australia a medium-power, low-priced car and a related utility vehicle to suit Australian conditions and designed to take account of locally available raw materials, with an output of 20,000 vehicles a year. Specifications for the car had already been submitted to the General Motors Corporation of Detroit, in the United States. Just as the war was ending an expert from the corporation visited Australia for the purpose of surveying the technical resources of the local automotive industry and of discovering the extent to which related industries would be able to support car manufacture. Though General Motors-Holden's had throughout the war received much help and technical guidance from the parent firm, it could not have achieved the manufacture of complete cars with the success that it did without further cooperation in engineering and research from the United States. A team of thirty Australian manufacturing and engineering technicians visited Detroit to study the latest methods of car manufacture,

[1] *The Motor Engine Vehicle Bounty Act 1939; The Motor Vehicle Agreement Act 1940.*

and to watch the construction and testing of three prototype models of the first Australian car. Late in 1946 Mr R. S. Begg (an engineer of General Motors Corporation) and a team of American specialists accompanied the thirty Australians on their return to Melbourne.

Then followed a long period of testing the American-built prototype cars under Australian road and weather conditions. Next, two locally-built prototypes, embodying all the modifications shown to be necessary by these tests, were given the most exhaustive tests of all. The test cars are said to have covered an aggregate of more than 250,000 miles. In the meantime General Motors-Holden's erected new manufacturing plants at Fishermen's Bend, Victoria, and Woodville, South Australia, reconverted existing plants from war production, and began to set in motion all the processes preliminary to volume production. The new car, known as the Holden, was first shown to the public on 29th November 1948. In January of the following year manufacture, without the aid of bounty or subsidy, began on a large scale. To many, the appearance of the Holden symbolised Australia's arrival as an industrial nation. An essential factor in this extension of the automotive industry was the wartime development of the engineering industry, without which progress would not have been so rapid.

Primary Industry. Mindful that primary industry was an integral part of the nation's economy, and in fact its mainstay, the Government gave thought during the later years of the war to the problem of re-establishing servicemen on the land and to regenerating rural industry, which had suffered considerably, especially early in the war, by the diversion of manpower and materials to the manufacture of munitions.

Determined that the many failures which attended the soldier settlements after the 1914-18 war should not be repeated, the Government formed the Rural Reconstruction Commission to investigate the future of Australia's primary industries. Surveying failures after the 1914-18 war the commission found that land had often been used for the wrong purpose: settlers had tried to grow wheat on areas suitable only for grazing, and orchards had been started in areas where the hail risk was too high. Often the earlier soldier settlers had lacked competent technical advice and guidance.

Clearly one of the first considerations was to ensure a wise selection of land. Officers of the Commonwealth War Service Land Settlement Division—men with appropriate technical qualifications and practical experience—made detailed studies of soil type and character, topography of the land, water supply, climatic conditions, situation of the land in relation to transport and communications, markets, and other relevant factors. In making these surveys organisations such as the Climatological Division of the Commonwealth Weather Bureau, the C.S.I.R. and the Commonwealth Bureau of Agricultural Economics gave much valuable help.

While this work was in progress, intending ex-servicemen settlers who had had adequate practical experience or training were given intensive

refresher courses in the principles of farming, covering modern developments in the methods of breeding and feeding animals, and recent advances in the scientific side of agricultural practice, including the effect of climate and soils on plant production.

By 30th September 1949 the Government had spent £9,500,000 on its settlement scheme and had bought 7,500,000 acres of land; some 4,705 settlers had been given free rural training, and 2,872 had been placed on farms. Judged by experience to the time of writing, the War Service Land Settlement Scheme has been far more successful than the settlement schemes tried after the 1914-18 war.

Much of the research into the production and use of wool initiated with the help of funds provided under the *Wool Publicity and Research Act 1936,* was of necessity either suspended or very much restricted during the early part of the war. Later in the war, however, the wool industry, aware of the rapidly increasing danger of competition from synthetic fibres, awoke to the necessity of providing even more substantial funds for research on wool. Ways and means of ensuring the widest application of the results of scientific research to the wool industry were considered, both by the Textile Advisory Panel of the Secondary Industries Commission and by a special Inter-departmental Committee[2] appointed by the War Cabinet in May 1944. On the strength of a report made by this committee, the Government brought down the *Wool Use Promotion Act 1945* which provided for the levying of a tax of 2s a bale (as compared with 6d a bale in 1936). Proceeds from the tax went to the Australian Wool Bureau (the reconstituted Wool Board) which used the money mainly for publicity and promoting the wider use of wool; some was used indirectly to support research through the award of fellowships which enabled science graduates to study at Leeds and other textile research centres overseas. At the same time the Government itself matched the growers' contribution bale for bale to build up a fund known as the Wool Research Trust Account. With the help of funds so raised during the next few years scientific research on wool in Australia was begun in earnest. The C.S.I.R.O. set up Wool Textile Research Laboratories in Melbourne, Geelong and Sydney in 1949.[3] Two years later the N.S.W. University of Technology, applying funds provided by the State Government, formed a School of Wool Technology.[4]

Probably the most significant of the C.S.I.R.O's efforts to help the wool industry in the first ten years after the war was the development of a method for controlling the rabbit population by means of a virus disease, myxomatosis, and the revelation of the importance of trace elements, especially of cobalt and copper, in the nutrition of sheep. By adding these and other trace elements to land which was not much better than desert,

[2] Comprising representatives of the C.S.I.R. and Departments of War Organisation of Industry, Post-war Reconstruction, Supply and Shipping, Commerce and Agriculture, and the Treasury.

[3] In charge of Dr F. G. Lennox, Dr M. Lipson and Mr V. D. Burgmann, respectively.

[4] In charge of Prof P. R. McMahon.

upwards of 1,000,000 acres in one scheme alone[5] were made suitable for the grazing of sheep. One authority estimated that before the introduction of the disease, rabbits destroyed pasturage that would have been sufficient to maintain another 50,000,000 to 75,000,000 sheep.[6]

Accompanying this increase in scientific research there were corresponding developments in facilities for training men for the textile industry. The Textile Advisory Board in its first report to the Secondary Industries Commission pointed out that if Australia was to expand her wool industry by increasing the proportion of wool processed and manufactured locally, it would be necessary to increase technical training facilities at all levels of the industry. Out of its recommendations came the setting up of a major training centre at Geelong and minor centres at Sydney and Melbourne.[7]

Power developments after the war. Reserves of generating capacity were seriously depleted as a result of the war, and in the years immediately after demands for power exceeded supply. The sudden growth of load was brought about by rapid industrial development, a great increase in the use of domestic appliances which were now being manufactured in large quantities, and the expansion of population brought about by immigration. As a result, Australia found herself for some years seriously harassed by shortages of electrical power. As in most countries of the world, power rationing was necessary; blackouts were experienced to some degree in most States and most severely in New South Wales.

Apart from the more urgent tasks of extending and rebuilding some existing metropolitan power stations, the notable trend after the war was to build power stations away from large cities.[8]

In the early days of power supply it was generally considered economical for power stations to be built near the centre of the area to which they supplied power. It was later found that the cost of transmitting large amounts of electrical power was, except in special circumstances, less than the cost of transporting high-grade coal. This being so, the obvious place to establish a power station, provided there were no overriding considerations, was as near the mouth of a coal mine as possible. One other limitation on the choice of sites had to be considered: there must be available ample supplies of cooling water for condensing purposes.

The trend towards decentralisation of thermal power stations was particularly noticeable in New South Wales, but in order to be near supplies of water they were still built mainly in positions near the coast and therefore vulnerable to enemy action. In 1955, within a radius of about 100 miles from Sydney, three thermal stations were under construction:

[5] This was an area in the Ninety Mile Desert whose reclamation was financed by the Australian Mutual Provident Society.

[6] "Science and Australia's Growing Agricultural Revolution", by Sir Ian Clunies-Ross, *National Development* No. 7 (1954).

[7] Textile College, Gordon Institute of Technology; Sydney Technical College; and Textile Trades School, Melbourne Technical College, respectively.

[8] V. J. F. Brain, "Some Observations on Electricity Supply on the Australian Mainland", *Journal of the Institute of Engineers of Australia,* Vol. 24 (1953), p. 123.

70 miles north of Sydney a 330-megawatt power station was being built on the shores of Lake Macquarie, where there was an unlimited supply of cooling water and also, within 3 miles of the station, an ample supply of coal from the newly-developed mine at Awaba in the Great Northern Seam; 60 miles south of Sydney, on the shores of Lake Illawarra, a 320-megawatt power station designed to use coal from a nearby mine; and finally, west of Lithgow at Wallerawang, a 240-megawatt power station designed to use open-cut coal from a nearby seam and cooling water from the Fish River.

Similar trends were evident in Victoria, South Australia and Western Australia, where even greater savings in transport costs were made by building power stations close to the deposits of low-grade coal which these States must perforce use to be independent of New South Wales. In South Australia it proved impracticable to build a large power station close to the Leigh Creek open-cut mine, owing to the inadequate supply of cooling water; even the less efficient, more costly cooling towers using a minimum of water proved to be out of the question. A compromise was reached by placing the station on the seaboard near Port Augusta. Similar reasons accounted for the building of a power station at Bunbury in Western Australia. The other States' growing independence of New South Wales for coal, accentuated by the war, was carried still further in the immediate post-war years, so that by 1951 the five States, which some thirty years before had drawn 63 per cent of their coal from New South Wales, drew only 23 per cent. This trend was advantageous from a defence point of view, and also made it possible to conserve high-grade coals for metallurgical coke and gas-making, for which they were technically so well suited.

Easily the most ambitious of all the post-war power developments was the Snowy River Scheme. For many years there had been discussions on how the waters of this, the most reliable of the mainland rivers, could be used, but owing to the extreme isolation of much of the region through which it flowed progress was slow. One of the first to appreciate the value of the river as a source of hydro-electric power was Mr W. Coun, Chief Electrical Engineer of the New South Wales Public Works Department, who during the first world war made two surveys, one in 1915 and the other in 1918. But the time was not yet ripe for such a scheme and no action was taken.

The next thirty years saw a succession of proposals and counter-proposals for the use of the Snowy River; most of them viewed the river and its potentialities from a State rather than a national point of view and usually with the emphasis on either power or irrigation. Even as late as 1944 a special committee appointed by the New South Wales Government to carry out further investigations on the possible use of the Snowy River for power and irrigation, considered irrigation mainly from the point of view of New South Wales. A committee appointed by the New South Wales Government in 1941 to enquire into the possible uses of the waters

of the Snowy proposed a plan to divert them to the Murrumbidgee near Cooma, primarily for the purpose of irrigating the Murrumbidgee Valley. Since the lower part of the Snowy River passes through Victoria these proposals did not find favour in that State. Another plan developed in considerable detail by Mr Olsen[9] of the Victorian State Electricity Commission favoured the idea of diverting the waters of the Snowy to the River Murray. This plan found a powerful supporter in Mr H. P. Moss, Controller of Electricity Supply to the Department of Munitions, who in a report to the Minister for Post-War Reconstruction recommended:

> that the Government be advised that the possibilities of the development of the Snowy River for both hydro-electricity generation and for water conservation appear to be much greater and of much wider significance than any previous investigation has shown, and that a close, detailed survey of certain features should be made immediately with a view to obtaining essential basic data necessary to confirm this possibility.[1]

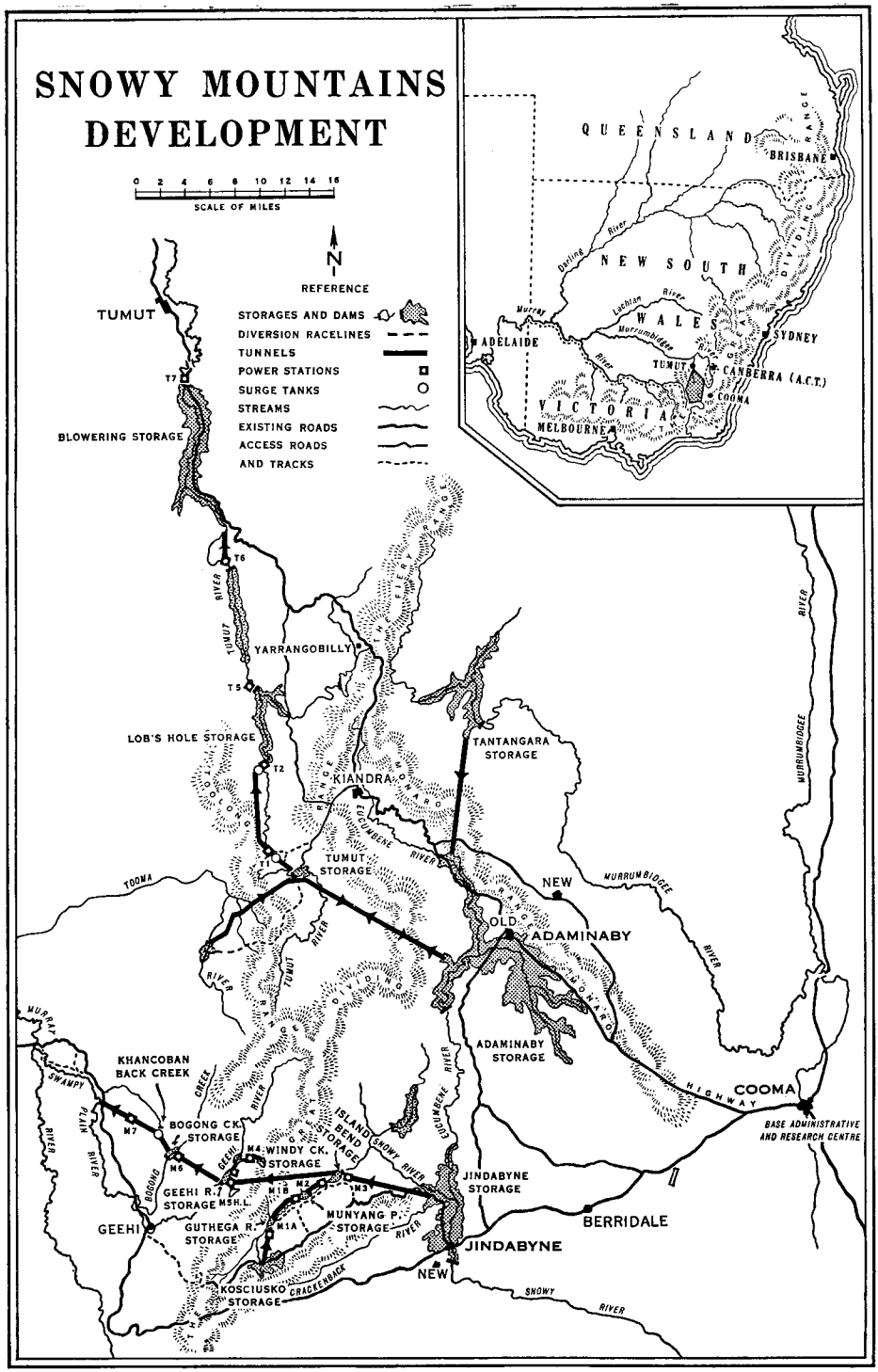
As the end of the war approached interest in the scheme was roughly equally divided between its potentialities for supplying power and for irrigation. On the one hand, the preoccupation of the Commonwealth with the supply of food to the Allied Forces in the South-West Pacific Area, and the realisation of the part played by the Murrumbidgee area in this effort, did much to focus attention on irrigation. The Commonwealth Rural Reconstruction Commission, for example, recommended in 1945 that "the maximum development of irrigation should be regarded as a national objective". On the other hand the expansion of secondary industry throughout Australia, and the needs of a population increasing rapidly because of large-scale immigration, did much to bring about a more general appreciation of the wider implications of the Snowy scheme as a source of power. Since it was clear that the interests of the Commonwealth, New South Wales and Victoria were all directly involved, it was essential that some properly constituted body on which they were all represented should be formed.

A more nearly national approach to the problem of using the waters of the Snowy River was made in 1946 when ministers of the Commonwealth, New South Wales and Victoria, with their technical advisers, met to consider the rival schemes and the rights and responsibilities of the States and of the Commonwealth Government. The conference decided that both schemes—the one proposed by New South Wales to divert the Snowy to the Murrumbidgee, and the Victorian proposal to divert it to the Murray—should be fully investigated. The results of this study, which were placed before a Premiers' Conference in 1947, led to the setting up of a Joint Commonwealth-States Technical Committee under the chair-

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[9] O. T. Olsen. Civil Investigation Engineer, Vic State Electricity Commission, 1926-50; Chief Investigating Engineer, Snowy Mountains Hydro-Electric Authority, 1950-55. Civil engineer; b. Sogne, Norway, 5 Sep 1890.

[1] Report on Snowy River Hydro-Electric Development, made in the first instance to the Secretary, Department of Munitions, 11 Oct 1944. Sent on to Minister for Post-War Reconstruction, 17 Oct 1944.


SNOWY MOUNTAINS DEVELOPMENT
0 2 4 6 8 10 12 14 16
SCALE OF MILES
N
REFERENCE
STORAGES AND DAMS
DIVERSION RACELINES
TUNNELS
POWER STATIONS
SURGE TANKS
STREAMS
EXISTING ROADS
ACCESS ROADS
AND TRACKS
QUEENSLAND
BRISBANE
NEW SOUTH WALES
SYDNEY
ADELAIDE
CANBERRA (A.C.T.)
VICTORIA
MELBOURNE
COOMA
TUMUT
TUMUT
BLOWERING STORAGE
T7
T6
T5
T2
T1
YARRANGOBILLY
LOB'S HOLE STORAGE
KIANDRA
TANTANGARA STORAGE
TUMUT STORAGE
OLD ADAMINABY
NEW ADAMINABY
ADAMINABY STORAGE
COOMA
BASE ADMINISTRATIVE AND RESEARCH CENTRE
KHANCOBAN
BACK CREEK
BOGONG CK. STORAGE
WINDY CK. STORAGE
ISLAND BEND STORAGE
GEEHI R.7 STORAGE
GUTHEGA R. STORAGE
MUNYANG P. STORAGE
JINDABYNE STORAGE
JINDABYNE
BERRIDALE
GEEHI
NEW
KOSCIUSKO STORAGE
M7
M6
M5
M4
M3
M2
M1B
M1A
TOOMA
MURRAY
SWAMPY PLAIN RIVER
BOGONG CREEK
GEEHI RIVER
TUMUT RIVER
SNOWY RIVER
EUCUMBENE RIVER
MURRUMBIDGEE RIVER
HIGHWAY
CRACKENBACK

manship of Dr Loder,[2] Director-General of the Commonwealth Department of Works and Housing. To carry out the proposals put forward by this committee concerning the scheme, which was now planned as the largest regional development yet undertaken in Australia, the Commonwealth Government brought into being in July 1949 the Snowy Mountains Hydro-Electric Authority. Mr Hudson[3] was appointed Commissioner to administer the authority and Mr Olsen, who was mainly responsible for the broad concept of the national Snowy Mountains project, was made Chief Designing Engineer.

In its final form, the scheme provided for the diversion of part of the waters of the Snowy River into the Murray and the remainder into the Murrumbidgee, in such a way as would ultimately make available some 2,000,000 acre feet of water for the irrigation of the two river valleys. It also provided for the development, when completed, of approximately 3,000,000 kilowatts of power—an amount exceeding the total capacity of all generating stations then operating in Australia. The first stage was completed early in 1955, when power from the Guthega station was fed into the New South Wales grid.

The discovery at Rum Jungle in the Northern Territory and at Mary Kathleen near Mount Isa, Queensland, of deposits of uranium reputed to be comparable in extent with the largest in other parts of the world, and the report in 1953 of the occurrence of flow oil in the Exmouth Gulf region of Western Australia, coinciding as they did with the initiation of the Snowy Mountain scheme and the decision to build an experimental nuclear reactor at Menai, New South Wales, combined to open up the prospects of supplying enough power to sustain a population many times the present one. Whatever factor or factors might one day set limits to Australia's development as an industrial nation, lack of power did not seem likely to be one of them. Scarcity of water seemed more likely to be a limiting factor.

Summing Up. What, in general terms, was the over-all effect of the war on Australian science and industry?

In science there was a slowing down of fundamental research and a preoccupation with the applications of science. This trend was common to most, if not all, countries at war. Australia continued to train scientists and engineers throughout the war without any serious diminution in numbers, so that it was possible to sustain fairly well the rapid developments of science in the post-war years. The successful application of science to war created a deep impression on the community at large and heightened its appreciation of the part played by science generally in the modern world. Consequently, after the war research received much stronger financial

[2] L. F. Loder, CBE; DEng. (Served 1st AIF.) Chief Engineer, Vic Country Roads Board, 1928-40; Chairman 1940-44; Director-General Allied Works 1944-45; Director-General, C'wealth Dept of Works, since 1945. B. Sale, Vic, 30 Dec 1896.

[3] Sir William Hudson, KBE; BSc. Engineer in charge construction Gallaway Hydro-electric Scheme, Scotland; chief construction engineer Woronora Dam; Commissioner, Snowy Mountains Hydro-Electric Authority, since 1949. B. Nelson, NZ, 27 Apr 1896.

support from governments than it had ever previously enjoyed in this country, and the output of scientific research reached new levels in quality and diversity.

Industry began to contribute its share. While many firms affiliated with oversea organisations continued to rely on their parent bodies for research and developmental work, there were signs that the larger and stronger of them were beginning to assume responsibilities of their own in these matters. A few large, essentially Australian firms also began to establish well-equipped laboratories intended for something more than routine scientific control of manufacturing processes. Firms in both groups also contributed considerable sums of money for the endowment of research fellowships at universities.

Industry met the challenge of war by displaying at all levels—from skilled workmen to engineers and scientists and executives—a resourcefulness and an ability to improvise which enabled it to solve many of the technical problems produced by isolation. For the first time the value of production of secondary industry overtook that of primary industry, as can be seen from the accompanying table.

Australian Production in Primary and Secondary Industry
(in £000,000's)

	Primary	Secondary
1937-38 . .	214	197
1942-43 . .	282	352
1944-45 . .	277	362
1953-54 . .	1,093	1,230

It is not suggested that the greater expansion of secondary industry as compared with that of primary industry was something peculiar to the war years. It had been going on for many years; the war merely accelerated the change. At the turn of the century only about 12 per cent of adults were employed in secondary industry as compared with 30 per cent in primary industry. By 1950 the proportions were almost completely reversed (17 per cent in primary and 28 per cent in secondary industry).

Engineering industry emerged from the war greatly strengthened in its capacity to undertake mass production, and with an appreciation of what was involved in meeting the exacting standards and specifications for making munitions. It was able to make a wider range of structural materials than ever before. Developments that might otherwise have been spread over 25 years were compressed into little more than five years. With this background of wartime experience, industry was ready to undertake, after the war, the manufacture of motor-cars, jet aircraft and television equipment.

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